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THE PHOTO-PITOMETER AND WATER WORKS LOSSES

By EDWARD S. COLE

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One of the foremost problems in water works engineering today is *waste*, which has grown to alarming proportions in many American cities, already involving vast expenditures for unnecessary extension of plants, besides adding an ever increasing burden in cost of operation. Let us briefly consider the nature of this waste and means for its control.

The ancient Romans struggled with a heavy loss of water from their costly aqueducts, as we are told by Frontinus, and water works men are still attacking the same old problem.

Among the effective instruments that are helpful in the study of waste is the portable *photo-pitometer*, which has greatly simplified the measurement of flow of water through the intricate network of our underground pipe systems.

These distribution systems, which are the most costly and vital part of a water works plant, consisting of a vast gridiron of cast-iron mains, aggregating hundreds of miles in the case of our large cities, with a total valuation of millions of dollars, have received far less scientific attention than the more conspicuous parts of a water works property. *Filtration* has benefited by the wonderful developments of sanitary

science, and a century of steam engineering has produced the high-duty *pumping engine;* but comparatively little has been done to improve the all-important pipe system.

The works manager has never had accurate information regarding the flow of water in the various parts of his pipe system without using expensive and cumbersome means. Costly extensions of mains have, therefore, been left to guess work and much money thrown away.

Analysis of consumption in districts has been well-nigh out of the question because of the great cost of existing methods for gauging the mains.

This lack of information is now unnecessary, for with the portable pitometer measurements of flow may be made cheaply at any point without loss of time, and there is no longer any excuse for permitting losses from the underground system to continue.

Pure water delivered under pressure through pipes which provide adequate fire capacity is by no means a cheap product, as a few figures may show.

The actual cost of supplying one million gallons of water in many of our American works varies widely from about $20 in some of our large cities to $300 or more in the case of some small plants unfavorably situated. The average for twenty-two cities reported to the New England Water Works Association for 1904 was about $92 per million gallons for operating expenses and interest on bonds. This list includes no city larger than Cleveland, Ohio, where the reported cost was about $23. In Chicago the cost of water has been estimated at $19 per million gallons on the same basis. There, for example, the distribution system has 2,000 miles of mains from 4 to 48 inches in diameter, valued at $16,000,000, or one-half of the cost of the entire Chicago water works system, which is placed at $32,000,000.

With the growing demand for pure water supplies, involving vast expenditures for filtration works, the cost of water is increasing. For example, the city of Philadelphia is now building filters to cost over $30,000,000, and the necessity of reducing waste is therefore keenly appreciated.

Broadly speaking, *waste* is not the generous or even lavish *use* of water by consumers, but rather refers to willful and careless *misuse*, to the streams which run continually from faulty house fixtures and from leaky underground pipes; but water works losses include also the very serious problem of illegal *use* of water by large-metered con-

sumers, generally for trade purposes, through "by-passes," which rob the city of much needed revenue.

The slip of pumps, whereby our statistics of water consumption are falsified, is responsible for more trouble than has been supposed, for although loss of action in the pumps causes no waste of water, it nevertheless calls for additional pumping capacity at great expense and increases the fuel account.

Waste of water is *the* great evil in our American water works systems, and its effect upon city finances is twofold: First, in the futile attempt to fill the "sieve," which our leaky systems resemble, large appropriations are needed yearly to increase the pumping capacity; and, second, the pipe system needs continual reënforcement to maintain adequate fire service over and above the useless losses which drain its capacity.

Useless waste may amount to half the total supply of a city, or even more. For example, in his report on water measurements Mr. Dexter Brackett, C.E., concludes that half the total supply of the Metropolitan District is wasted, and a waste of one-half is evidently a serious matter. In New York City a recent report by Mr. James H. Fuertes, C.E., places the waste and unaccounted-for loss at 43 per cent. of the total supply, while J. R. Freeman, D.Sc., some years ago estimated the preventable waste in Manhattan at about 70 per cent.

In a recent report on water waste in Chicago, Mr. John Ericson, C.E., puts the probable waste at 76 per cent. of the total pumpage, and shows that $6,000,000 will be needed in the next ten years for tunnels and pumping plants alone if the present wasteful conditions go on. Whereas, if means are taken to control these losses, this great outlay may be avoided, and at the same time a greater saving made in extensions to the distribution system; for if one-half the supply is wasted the pumps must force twice as much water into the mains, and, since friction increases as the square of velocity, this doubling of the consumption through waste creates three times more loss by friction. The great cost of reënforcing a $16,000,000 pipe system does not need to be enlarged upon. Thus we see that the effect of waste on city finances *cannot* be ignored.

The principle of accurate accounting which is taken for granted in private business is peculiarly needed in water works management, but for lack of a cheap and portable meter it has as yet scarcely been applied in this country.

What is a fair and reasonable supply?

Let it be understood first of all that there can be no such thing as a standard per capita consumption by which cities may be compared one with another. Much of the controversy as to what constitutes an adequate water supply arises from lack of knowledge regarding the special requirements of different cities. It is folly to compare statistics of total per capita consumption without first separating trade and public uses from ordinary domestic demands. Then again the population per mile of main, the amount of lawn sprinkling per capita, and, above all, the relative luxury and personal habits of the several classes constituting the population of a city must be considered.

The very wasteful city of Buffalo, which has a total use per capita of over three hundred gallons, has a metered consumption for trade purposes alone of forty-six gallons per capita, more than the supply of Fall River for all purposes. Evidently such cities cannot be compared by their per capita consumption where they differ so widely in the trade use of water.

There is, however, ample opportunity for a study of definite and carefully classified uses, such as that made recently for the Metropolitan Water District (Boston) by Mr. Dexter Brackett, C.E., in which he gives the following analysis, based largely upon actual measurement:

Domestic use	25.0 gallons per capita
Manufacturing and trade use	23.5 gallons per capita
Public use	7.0 gallons per capita
Total	55.5 gallons per capita

or less than sixty gallons daily for each man, woman, and child. Whereas the Metropolitan District actually receives about 122 gallons per capita daily.

In other cities we have a reported total consumption per capita ranging from that in

Buffalo	over 300
Pittsburg and Philadelphia	over 200
New York, Chicago, St. Louis, and Boston	from 130 to 160
Providence, Worcester, Fall River, and Milwaukee [largely metered cities]	40 to 80

Abroad one finds such cities as London, Liverpool, Manchester, Glasgow, etc., reporting from thirty to sixty gallons. But there we

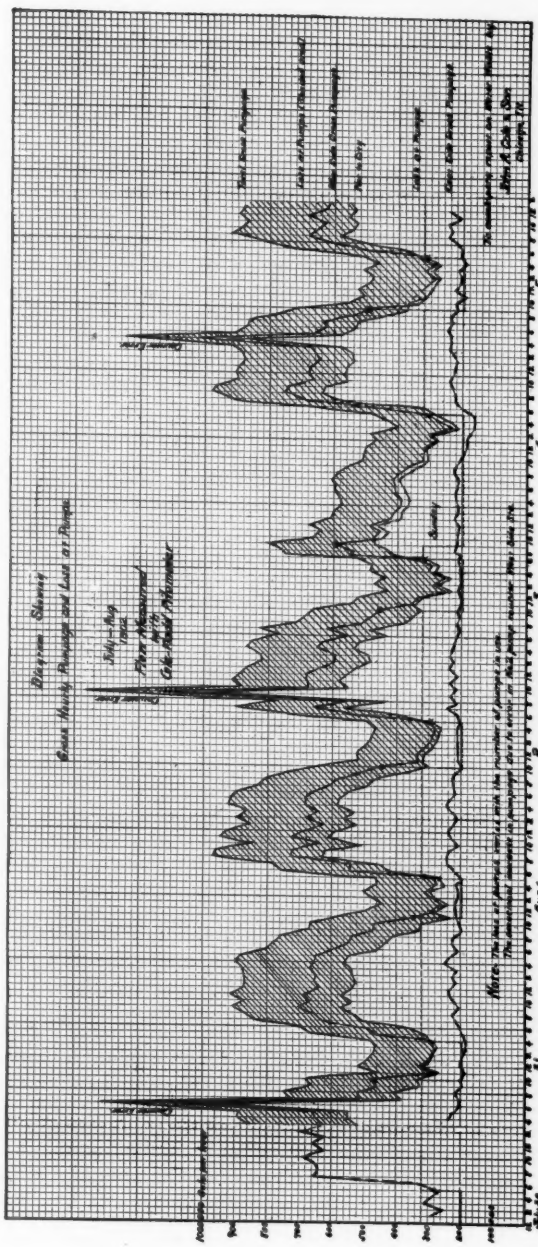

FIG. 1.—TOTAL PUMPAGE TO CITY AS MEASURED BY PITOMETER AND THE REPORTED PLUNGER DISPLACEMENT FOR SEVEN DAYS
Shaded area represents the loss by "slip"

find that a policy of waste restriction has been highly developed, which we will consider in detail later.

In this wide range of supply to American cities the reported figures are liable to be in error from an unsuspected slippage in the pumps. One of the first discoveries to the credit of the pitometer was in a city of about 125,000 population, which had been reporting 33 per cent. more water than was actually leaving the pumps.

Since this illuminating experience, pitometer tests show that leaky pumps are the rule rather than the exception, and a loss of from 25 to 50 per cent. is by no means unheard of even in engines of the highest type and largest size.

A wide variation in per capita consumption is due, as has been shown, to *trade use*, which will vary as cities are largely residential or are devoted mainly to commerce and manufacture.

Public uses, while but a comparatively small part of the total consumption, including the supply to public buildings, schools, hospitals, etc., are an important element. Street sprinkling, sewer flushing, and fire extinguishing call for attention when reducing the supply to a per capita daily standard.

Domestic consumption varies, as already stated, according to the habits of the people, and upon this point we are able to form a well-based opinion as to what constitutes a reasonable allowance.

In Worcester, Massachusetts, the total domestic use per capita, as shown by meters, is 16.8 gallons, varying from twelve gallons in the cheaper houses to twenty-three gallons in the best residence streets.

In Fall River the average class of dwellings, generally with bath and water-closet, use about eight gallons per capita daily, while in the most expensive houses the consumption is reported as twenty-five gallons. Boston apartment houses varied from about sixteen to fifty-nine gallons per capita daily, according to cost.

We should remember that these figures are for actual house requirements by meter measurements, and take no account of waste in the service pipe beyond the meter or in the street mains.

In Columbus, Ohio, a city with 125,000 population, there were in 1902 8,000 meters, and among 2,000 of these, taken at random from the books, 650 indicated a daily consumption of less than fifteen gallons per capita. It follows, then, that in fully one-third of all the houses in this city the use per capita was less than fifteen gallons per day, based on the meter statements. These 2,000 meters, as a whole, averaged sixty-five gallons per capita daily.

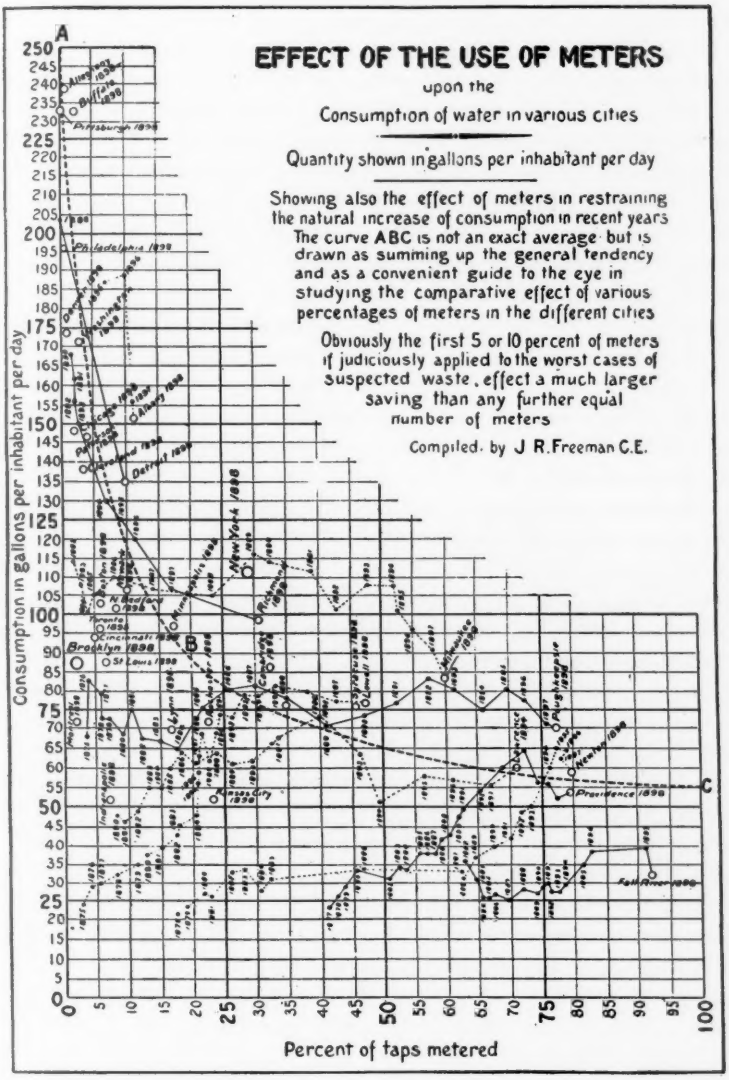
EFFECT OF THE USE OF METERS
upon the
Consumption of water in various cities
Quantity shown in gallons per inhabitant per day
Showing also the effect of meters in restraining the natural increase of consumption in recent years
The curve ABC is not an exact average but is drawn as summing up the general tendency and as a convenient guide to the eye in studying the comparative effect of various percentages of meters in the different cities
Obviously the first 5 or 10 percent of meters if judiciously applied to the worst cases of suspected waste, effect a much larger saving than any further equal number of meters
Compiled by J R. Freeman C.E.
Consumption in gallons per inhabitant per day
Percent of taps metered
A
B
C
Providence 1898
Brooklyn 1898
New York 1898
Fall River 1899

FIG. 2.—DIAGRAM ILLUSTRATING THE COMPARATIVELY SMALL SAVING BY THE APPLICATION OF METERS TO MORE THAN 40 PER CENT. OF THE CONSUMERS

An examination of the hourly records of pumpage in cities is very convincing as to the existence of waste. The notable feature of such records is that the apparent consumption is always high, even at the dead of night.

While we cannot judge of the relative wastefulness in various cities by a comparison of the per capita consumption, we find in reviewing statistics that the use of meters is always attended with a reduction of waste. An interesting diagram (Fig. 2), prepared by Mr. John R. Freeman, gives the use per capita of many cities and the percentage of taps metered in each. No better argument for the judicious use of meters should be needed, for the excellent effect of placing meters on about 40 per cent. of the consumers is plainly shown. This diagram also indicates that it is not economy to place meters upon more than about 40 per cent. of the premises taking water, if all trade uses and the more wasteful consumers are included.

We should also note that these communities having the largest percentage of taps metered and the smallest consumption are cities of moderate size. Here undoubtedly the demands are not as great as in the largest cities, where, as a rule, less than 10 per cent. of the taps are as yet metered. A meter system should always be supplemented by work for restricting losses in street mains and services beyond the reach of meters. There are many sources of waste, of which the chief may be defined as follows:

1. Defective plumbing in houses.
2. Willful waste, such as allowing water to run to prevent freezing, extravagant use of hose, etc.
3. Leaks beyond the consumer's premises in mains and service pipes.
4. Slip of pumps and careless station use.
5. Surreptitious uses not paid for.

(1) *Defective plumbing* is a well-known source of waste, largely due to our American habit of permitting the use of cheap and inferior fixtures, and the ordinary house meter certainly stands guard over it, for a meter makes each householder his own inspector. The admirable English practice of requiring all fixtures to pass official inspection could, if adopted in this country, accomplish great results.

(2) *Willful waste* undoubtedly exists. Many persons will let a stream of water run rather than pay a plumber for making repairs, and few realize how much a small stream will waste in twenty-four

hours. An ordinary faucet on a first floor may run as much as 5,000 gallons a day.

(3) *Leaks* beyond the reach of the house meter are undoubtedly larger than supposed, as evidenced by recent tests and meter comparisons.

In a large number of cities, having practically every tap metered, there is usually a discrepancy of from 30 to 50 per cent. between the total pumpage and the total meter registration. This unmistakable loss still remains after allowing for unmetered public uses, fires, and for slip of pumps. The inevitable conclusion is that water is leaking underground from mains and services. Now in the 2,000 miles of water mains in Chicago, for instance, there are fully one million joints of all sizes in mains alone, and no one knows how many leaks from a mere drip to a heavy stream may be flowing into the sandy soil or near-by sewer without showing on the surface. A distribution system of this size will also have several hundred thousand small service pipes, with an average length of perhaps 50 feet. These pipes are often of wrought iron, which may soon be perforated by corrosion. Leaky, broken, and abandoned service pipes are responsible for much waste which, because of a porous soil, may not give warning at the surface.

Mains should certainly be tight and services sound. In an entirely new system, ranging in size from 4-inch to 16-inch cast-iron pipe, under fifty pounds pressure, and before any service pipes were attached, a test is reported, showing a leakage of but one gallon per minute per mile of main. Such tests as this indicate that a well-laid system may be practically tight.

Some have thought that a large allowance should be made for defects in meters, but the large loss of water unaccounted for by total meter registration can hardly be caused by error in the meters themselves. In 1897 Mr. John A. Cole, C.E., had careful tests made of 1,064 meters in Des Moines, Iowa, which had been in use from one to fifteen years. Meters suspected of slip were mainly chosen, and the results showed an average loss of registration of only about 1½ per cent.

(4) *Slip of Pumps and Careless Station Use.* — All of the reported pumpage does not reach the mains because of what is known as "slip" and "station use" at the pumps. It is customary to make only a very small correction for this loss, and, in fact, the statistics of most cities are based upon the full amount of water displaced by the pump plungers, the almost universal method being to multiply the recorded strokes of each engine by the theoretical number of gallons displaced

by its plungers per stroke. The only merit of this method lies in its simplicity. That it is liable to gross error has been found on many occasions when the actual discharge from a pump has been measured and compared with the counter record. Discrepancies of 25 to 40 per cent. and more have been repeatedly found in pumping engines by pitometer tests.

This loss should always be determined and deducted from the reported supply to a city. Slip at the pumps is not only misleading,

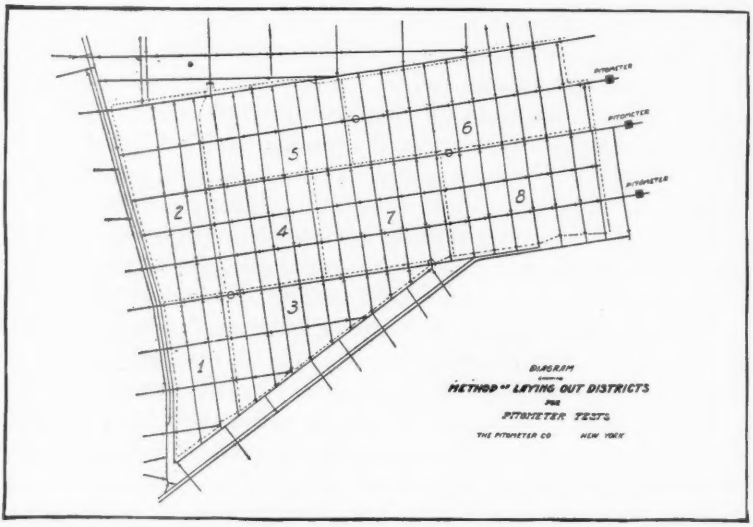

FIG. 3.—A SECTION OF THE NEW YORK CITY PIPE SYSTEM SHOWING METHOD OF GAUGING BY PITOMETERS AND SUBDIVISION

but requires the same pump capacity, steam, and fuel as though the full plunger displacement were discharged into the mains.

This slip leakage, developed by wear of the plunger and valves, permits the water to "slip" by, simply churning back and forth, doing no good, but absorbing power and valuable pumping capacity, which is worse. Such loss is more likely to become serious in the horizontal inside-packed type of pump. The presence of sand or grit in the water will cause wear between plunger and ring, valve and seat, until in a few months the loss may be enormous.

Electrolysis has been the cause of much deterioration of mains and

services in a large number of cities. The leaks so produced are difficult to find, and the full extent of the damage can be discovered only by making a careful and minute survey of the system, street by street, by voltmeter and pitometer.

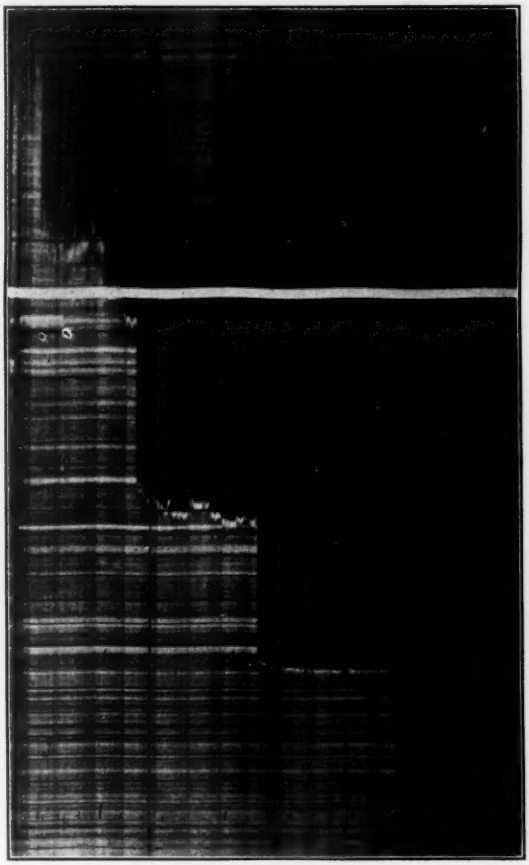

FIG. 4.—A PITOMETER RECORD REDUCED SHOWING "DROP" IN FLOW AS GATES ARE SHUT

The extent of water waste has, perhaps, been sufficiently described, and the remedy may now be considered.

In a water-waste investigation a city is divided into large districts, closing all the main gates but one, placing a recording pitometer on the

inlet to the district (Fig. 3), and keeping a record of the inflow. This total use in connection with the district population and the amount registered by the private meters will give a good idea of the wastefulness of the section, taken as a whole, the rate of night use being most significant. In case the district shows a reasonable rate it may be passed by, thereby saving the expense and trouble of house to house inspection.

If, on the other hand, an excessive consumption per capita is indicated, the next step is to analyze the supply by streets, using the pitometer to record the "drop" in flow as valves are closed one after another. All streets do not use water at the same rate per tap, and for this reason it is easy to find an unusual flow. When the night waste has been localized within a few blocks this smaller section is enclosed by itself and supplied through its own waste meter.

Then, if necessary, the curb cocks are closed one after another at night, the waste meter at the same time continuously recording the rate of flow, so that when a house is reached which has a leaky service pipe or fixtures the pitometer on the main will, on closing the curb cock, record a "drop," which is the rate of waste. In this way a record showing the condition of every house on the street is obtained and waste is located, which can be further defined by house to house inspections. The waste meter record not only locates the loss on certain premises, but measures it exactly.

This American method by the use of the pitometer is a development of the long established Deacon system, which, although still very much depended upon in England, has not proved popular in this country, although for several years it was used in Boston with success.

Every large city should organize its own department for the systematic detection of waste according to some such plan as has been outlined. The work calls for the intelligent and skilled supervision of an engineer, and must be persistently followed up for years, if need be, to secure the final results. The time required to traverse a square mile depends on the number of waste meters employed and upon the physical condition of the pipe system. Several districts may be inspected at the same time under the direction of one competent head. Experience has amply proved the value of such work, for its results are felt at once, and the cost is repaid out of savings as the investigation proceeds.

The increase of income and the saving of expenditure for new pumps and mains will net millions of dollars to taxpayers. Purification

works, which sooner or later will be demanded in many of our large cities, can be built from funds so saved without becoming a burden. *Waste prevention* and *water purification* are now the order of the day, and they ought to go hand in hand.

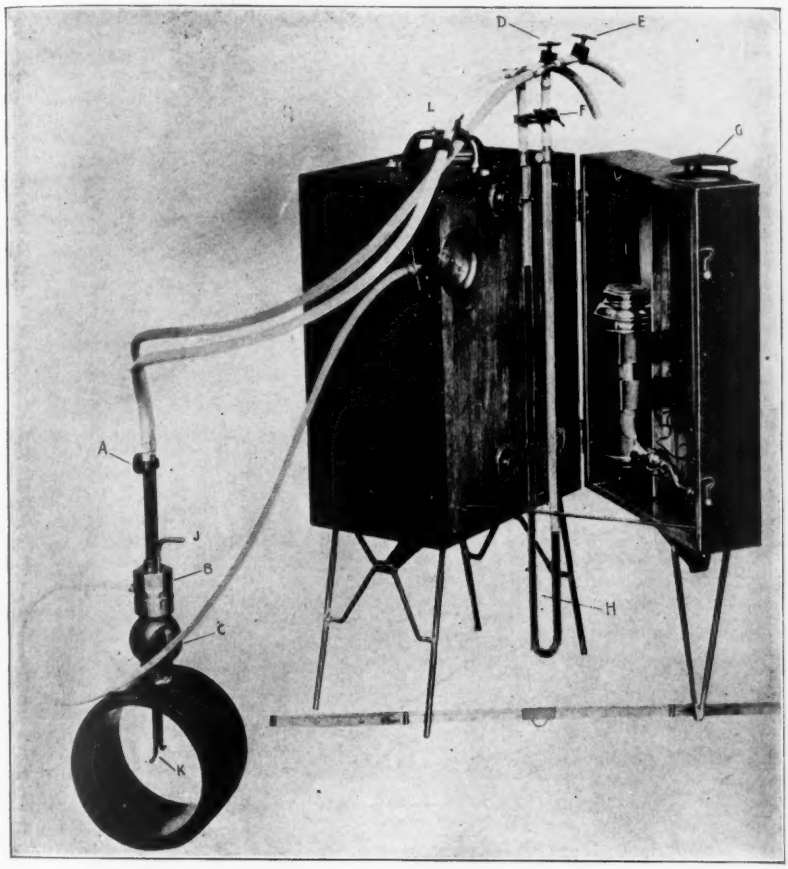

FIG. 5.—THE PHOTO-PITOMETER

The pitometer as described was developed by the writer about ten years ago for use as a waste meter in an investigation at Terre Haute, Indiana. The instrument proved to be accurate and efficient, and has since been adopted on important tests in our largest cities. Its funda-

mental principle was discovered by the French engineer, Pitot, about the year 1732 and later improved by D'Arcy for use in open channels.

The application to water mains under pressure has been developed

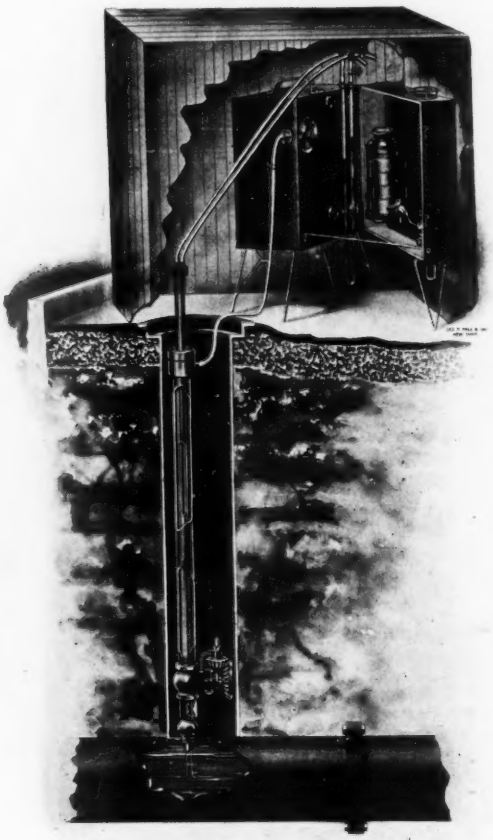

FIG. 6.—THE ROD METER, STREET CONNECTION, AND SHELTER BOX

during recent years, until the Pitot tube may now be classed among the most useful and accurate engineering instruments.

This instrument is primarily a rate meter, depending as it does upon the velocity of water within the main. It does not directly indicate the total discharge in cubic feet in a given time, as with ordinary meters,

but this elimination of the time element is necessary in a waste meter, for by the changes in rate we are able to study the effect of closing valves and service cocks in such an investigation as just described.

The instrument may be described as follows: Two small tubes bent at their lower ends, with carefully formed orifices, are held in a suitable cap, which screws upon a standard 1-inch corporation cock, through which the tubes may readily be introduced into any main and as easily withdrawn. The rod meter is the most recent development of the instrument, by which the slender tubes are enclosed in an oval sheath, which enables the meter to be introduced into the main from the surface of a city street through a "street connection" which is permanently set upon the main. Wherever street connections are set they are always available for use, and by the application of the portable rod meter the flow in the main can at once be ascertained.

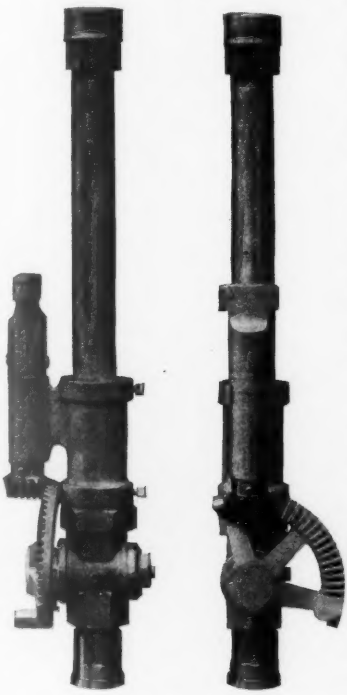

FIG. 7.—THE PITOMETER STREET CONNECTION

Heavy cloth insertion rubber tubing connects the orifice tubes with a long glass manometer, or U-tube, and blow-off cocks are provided to remove air from the instrument. The U-tube is half filled with a mixture of carbon tetrachloride and gasoline, having a specific gravity of 1.25, and when in use the water from the pipe fills all the remaining space in the U-tube and connections. The orifices are set to receive the maximum velocity within the main, which is usually near the centre, and is indicated by the deflection in the manometer. This deflection, by virtue of the differential action of the water and the slightly heavier and insoluble liquid, is just four times that due to the actual difference of water head on the orifices produced by the flowing stream. The current impinges directly on one orifice, but the other is turned down

stream, and gives something less than the static head within the main, thus increasing the difference of pressure produced. This difference is then multiplied in the U-tube, the result being that even a low velocity within the pipe produces a readable deflection. Without this effect the Pitot tube would hardly indicate a velocity less than 1 foot per second, while the pitometer is reliable at velocities as low as 6 inches per second. At ordinary velocities the U-tube deflections may run up to 24 inches, and therefore need not be read with any great nicety.

The photo-recorder consists of a portable box in which a drum carrying Velox paper revolves before a fine vertical slit, just in front of which is locked one leg of the U-tube in such a position that the rays of light from an oil lamp will be partly intercepted on their way through the colored liquid in the lower half of the manometer. As the liquid rises and falls with the velocity in the pipe, it will record on the Velox paper a line or band of shade whose ordinates vary according to the well-known formula:

$$V = c\sqrt{2gh},$$

in which h is one-quarter of the U-tube deflection in feet, or half of the recorded ordinate on the paper. A twelve-hour photographic record is 18 inches long and 10 inches high. Autographic horizontal lines are formed by notches in the drum slit, spaced so as to correct for the angularity of the light and enable the true deflection to be readily taken from the diagram at any point.

An autographic record of variation in static pressure is superimposed upon the flow diagram by means of a suitably connected gauge and movable finger, which intercepts the light passing through the U-tube and slot. This pressure record is of great value in the interpretation of any sudden change in the rate of flow, for by its aid we may know whether the observed change in rate is caused by a corresponding variation in pump pressure, as in "direct systems," or by the change in rate of draught within the district under investigation. Thus the detection of waste is facilitated.

The accuracy of the pitometer has been established by many weir tests, and also by calibration in open channels, where the absolute velocities indicated by the instrument were compared with float measurements.

The calibration constant c of the orifices has thus been experimentally determined to be .80 in our formula.

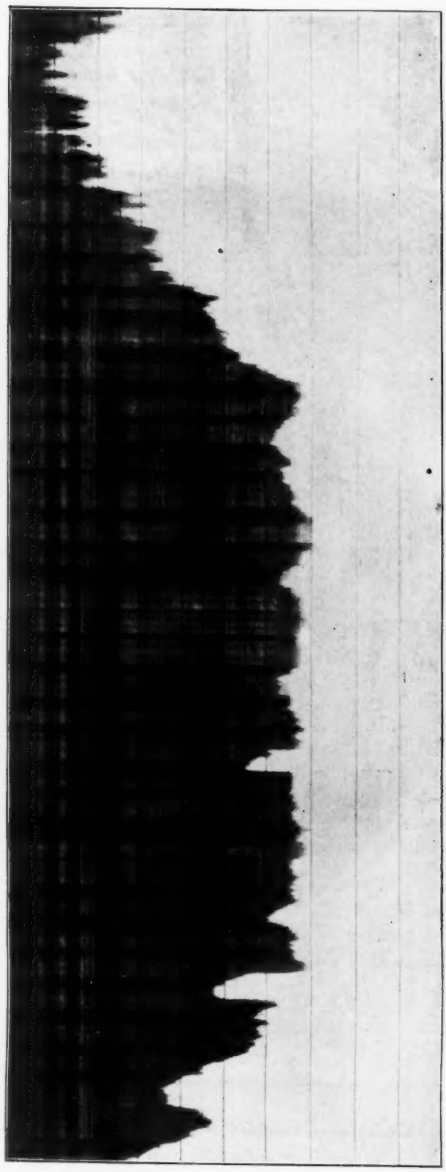

FIG. 8.—A 24-HOUR PHOTO RECORD (REDUCED) OF CONSUMPTION BY A CITY RESIDENCE DISTRICT HAVING A POPULATION OF 46,000

Minimum rate of night consumption is shown to be 1.6 gallons per capita per hour

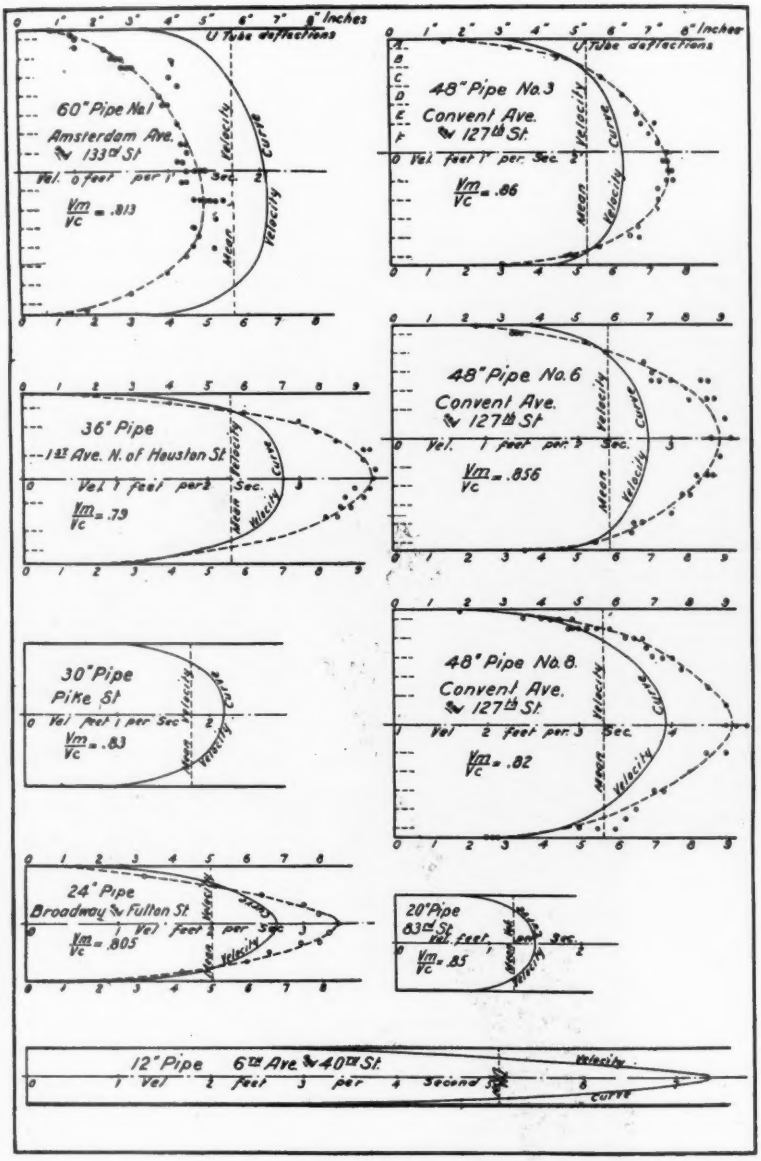

FIG. 9.—TYPICAL CURVES SHOWING DISTRIBUTION OF VELOCITY IN CROSS-SECTION OF PIPE

The full-line curves show velocities; the dotted line curves show the pitometer U-tube deflections

We have, then,

$$V = .8\sqrt{\frac{2gd}{4}} = 3.212\sqrt{d},$$

in which d is the U-tube deflection in feet. The actual velocity of the water is indicated in this way wherever the orifices may be placed within

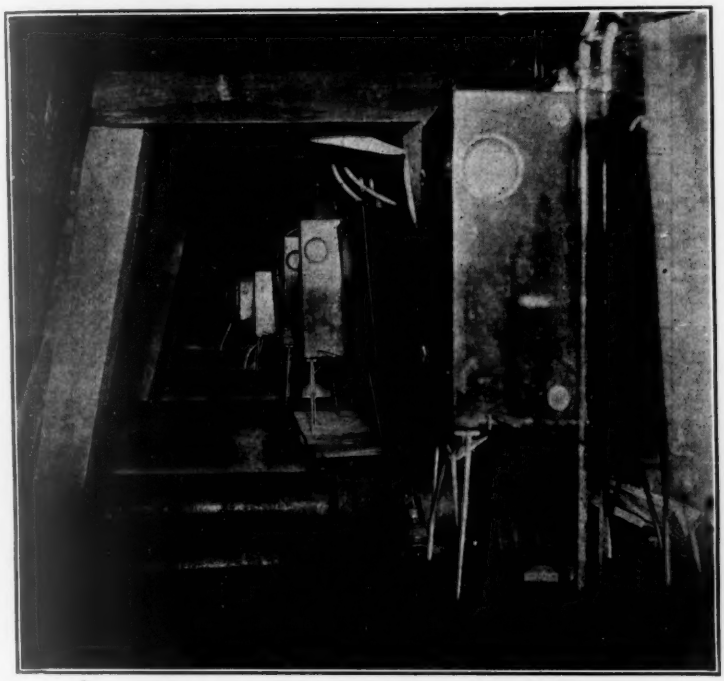

FIG. 10.—PITOMETERS RECORDING THE FLOW OF EIGHT 48-INCH AQUEDUCT MAINS SUPPLYING MANHATTAN, NEW YORK CITY

a pipe, and by completely traversing a given pipe section on one or two diameters the ratio of mean to maximum velocity is computed at some one rate of flow.

This ratio once determined for a given pipe holds good at all velocities. The orifices are permanently set to give the centre or maximum velocity within the pipe, reading off the mean velocity and the discharge from a table prepared for the particular size of pipe and veloc-

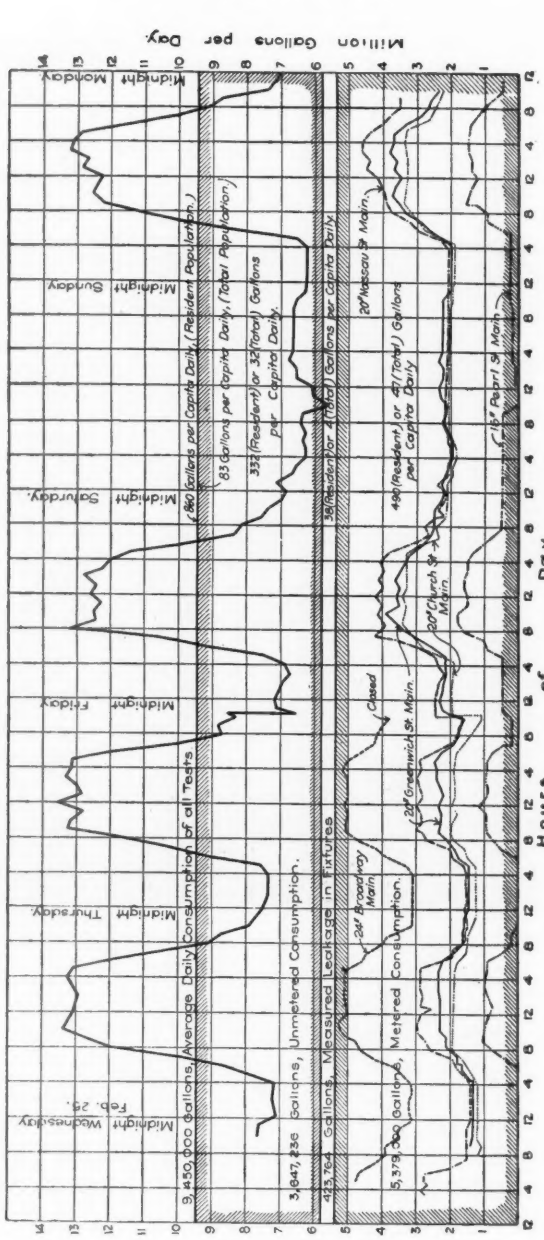
Million Gallons per Day.
Midnight Wednesday Feb. 25.
Midnight Thursday
Midnight Friday
Midnight Saturday.
Midnight Sunday
Midnight Monday.
9,430,000 Gallons, Average Daily Consumption of all Tests
3,647,236 Gallons, Unmetered Consumption.
433,764 Gallons, Measured Leakage in Fixtures.
5,379,300 Gallons, Metered Consumption.
24" Broadway Main
24" Greenwich St. Main
Closed
20" Church St. Main
20" Nassau St. Main
16" Pearl St. Main
880 Gallons per Capita Daily (Resident Population.)
83 Gallons per Capita Daily. (Total Population)
352 (Resident) or 32 (Total) Gallons per Capita Daily.
38 (Resident) or 4 (Total) Gallons per Capita Daily
498 (Resident) or 47 (Total) Gallons per Capita Daily
Hours of Day.
Million Gallons per Day.

FIG. 11.—THE FINANCIAL DISTRICT OF NEW YORK, IN WHICH PRACTICALLY ALL BUILDINGS ARE METERED

A five-day gauging of supply by pitometers shows that the meters of this section account for but little more than half of the actual supply

ity ratio. This method leaves nothing uncertain. The mean velocity computed from a traverse of a pipe with the pitometer has been checked by careful weir measurement of the flow in pipes from 4 inches to 72 inches in diameter, with close agreement. With careful use, discharge in pipes may be determined by the pitometer within 2 or 3 per cent. of the truth, an accuracy which is highly satisfactory for the solution of practical hydraulic problems.

CONTRIBUTIONS FROM THE
SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION
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THE DETERMINATION OF THE ORGANIC NITROGEN IN SEWAGE BY THE KJELDAHL PROCESS

II. STUDIES ON DIRECT NESSLERIZATION

BY LEYLAND WHIPPLE

THE value of a method of analysis, when used in routine work, becomes to a considerable extent a function of the rapidity with which it may be carried out. In no case, perhaps, is this better exemplified than in the estimation of organic nitrogen by the Kjeldahl process, in sanitary water and sewage analysis. This determination, by far the most important, from the viewpoint of interpretation, involves one of the longest procedures, and is consequently not generally employed.

Several attempts have been made to shorten this process by nesslerizing the diluted digestate directly, without distillation. Unless special precautions are taken, however, certain constituents of the digestate are found to react with the Nessler's reagent, producing a turbidity in the presence of which it is not possible to make close comparisons of the color of the nesslerized tube with that of the standard. Of the heretofore published methods, only one, that of Kimberly and Roberts (1906), has been found to be uniformly successful under local conditions, and this method has in our hands failed to yield satisfactory results.

It is the purpose of this paper to present the results of some experiments carried out in this laboratory on direct reading of Kjeldahl digestates, and to give a procedure which has been found entirely successful here and which may be of application elsewhere.

PREVIOUS RESULTS

Direct reading of diluted Kjeldahl digestates has been the subject of investigation both in this country and abroad. Rideal (1901) gives a procedure which consists in neutralizing with an excess of caustic soda, diluting to a definite volume, allowing to settle for a number of

hours, and pipetting off a portion of the clear supernatant liquid for nesslerization.

Phelps (1904), at this laboratory, tried making up the digested sample to volume, taking out the requisite amount, neutralizing and making up to 50 c.c. in the Nessler tube. He found that in about half the cases a turbidity was produced on adding the Nessler reagent.

McGowan (1904) attempted to use a modification of the Rideal method by making *just neutral* with hydrate, and in some cases adding potassium oxalate to precipitate the calcium. He found, also, that in more than half the total number of determinations the tubes were too turbid to read. Furthermore, he pointed out a probable loss of ammonia by adsorption in the precipitate formed. He attributed the turbidity to the insufficient precipitation of the calcium.

As a result of an extended investigation carried out at the Columbus Sewage Testing Station, Kimberly and Roberts (1906) published a modification of the processes of Rideal and McGowan, which consisted in diluting the digestate to 100 c.c., nearly neutralizing with sodium hydrate, cooling, adding a slight excess of hydrate and then 2 c.c. of a 10 per cent. solution of sodium carbonate solution, diluting to a known volume, allowing to settle six hours, and nesslerizing a portion of the clear liquid. This method was the result of a series of investigations into the causes of turbidity, the latter being finally attributed to the presence of calcium and magnesium salts. Kimberly showed that an amount of calcium up to 2.5 mg. per nesslerized tube would not produce turbidity, but that in greater concentrations it would interfere with the process. He used a slight excess of caustic to precipitate the magnesium, and sodium carbonate to precipitate calcium. The long period of settling was necessary in order to remove the slow-forming calcium carbonate.

He states, further, that potassium permanganate cannot be used to complete the digestion, as the manganous sulphate formed will cause turbidity on nesslerizing. The cooling before final neutralization was recommended to avoid the escape of ammonium hydrate from the hot solution. He found it necessary, also, to purify the soda by permanganate, in order to remove iron and organic impurities. In his experiments on the accuracy of the process, he found that adsorption was a negligible factor. In numerous comparative determinations by distillation and direct nesslerization close agreements were obtained.

In an endeavor to obtain a method for the direct reading of Kjeldahl digestates at this laboratory, the method of Kimberly and Roberts was

tried, but failed to yield satisfactory results, it being found impossible to obtain clear tubes upon nesslerization. We have therefore further investigated the causes tending to produce turbidity, and have succeeded in devising a modification of the Rideal method which is successful under conditions found here, and which should be applicable to all sewages except under conditions which will be defined later on in this paper.

Causes of Turbidity in the Tube

The causes of the turbid tube have been variously attributed to the presence of calcium, magnesium, sulphate ions, and manganous salts, resulting from the use of potassium permanganate to complete the digestion.

Kimberly and Roberts have shown that sulphate ions are not one of the disturbing causes. In regard to manganous salts, it is a well-known fact that permanganate is rapidly hydrolyzed and reduced in dilute solutions, either weakly acid or alkaline, and is then precipitated on standing. When used to complete the digestion, the permanganate is at once reduced by the hot acid, and settles out of the diluted digestate as a basic salt. Moreover, should traces of manganous sulphate yet remain in solution, they will be precipitated upon neutralization. Permanganate has been used throughout the present investigation and has never given rise to any cloudiness in the tube.

We have confirmed the conclusion of Kimberly and Roberts that calcium may be present in the tube up to 2.5 mg. without producing turbidity. As an amount of sewage is normally taken which will give a reading of not more than five on the colorimetric standards, corresponding to .05 mg. of nitrogen, it is clear that we cannot have more than fifty parts of calcium to one of nitrogen. That is, in a sewage in which the calcium content is not over fifty times that of the nitrogen, tubes which will give a reading of five or less may be nesslerized directly without any special precautions being taken to remove the calcium. Except in the case of a good sand-filter effluent from a sewage very high in calcium, this ratio will seldom be realized. Even in cases where this ratio is exceeded, it might be advisable to use a less amount of the sample, so as to make the reading about two on the standards. This would increase the allowable ratio of calcium to nitrogen to 125.

Similarly the allowable ratio of magnesium to nitrogen was determined, and found to be so low that the removal of magnesium appears

to be an essential detail. An amount of magnesium in the tube of over .025 mg. will produce either a cloudiness or a considerable deepening of the color of the reagent. To determine the amount of excess hydrate required to effect sufficient precipitation of magnesium salts, a sample was made up containing about 0.12 mg. nitrogen as ammonium chloride, 2.5 mg. magnesium as chloride, and digested with 5 c.c. of sulphuric acid in the usual way, with the addition of permanganate. The digestate was diluted to 250 c.c., and successive portions of 10 c.c. each were neutralized with varying amounts of a 5 per cent. solution of sodium hydrate, starting with an amount just sufficient to neutralize the acid, as determined by a test portion, using phenolphthalein as an indicator. The samples were filtered through washed filters into Nessler tubes, and the filter and precipitate then washed with ammonia free water.

The results of this experiment are shown in the following table:

Tube.	5 per cent. hydrate. c.c.	Reading.	Remark.	Corrected reading.*
1	7.2	. .	Very turbid	. .
2	7.5	. .	Very turbid	. .
3	8.0	About 5.0	Considerably turbid	4.8
4	9.0	5.0	Slightly turbid	4.8
5	10.0	4.8	Clear	4.6
6	12.0	4.9	Clear	4.7
7	15.0	5.0	Very slightly turbid	4.7
8	20.0	About 5.8	Considerably turbid	5.4

* A blank on 10 c.c. of the hydrate gave a reading of 0.2; the figures in this column have had this correction applied.

This indicates that after neutralization an excess of hydrate must be added equivalent to 1.5 grams per 100 c.c. of the diluted digestate, in order to effect a satisfactory removal of the magnesium. Furthermore, it is indicated, and we have further confirmed the fact, that the reading is not appreciably affected by an excess of hydrate unless in sufficient amount to itself cause turbidity. This amount has been found to be about 0.35 gram per 50 c.c. Nessler tube.

The addition of copper sulphate to hasten the digestion has no effect on the final result, as the copper is entirely removed by the hydrate.

It appears, therefore, that magnesium salts are one of the principal causes of turbid Nessler tubes; that the magnesium can be satisfactorily removed by an excess of sodium hydrate; and that this necessary excess is not in itself sufficient to produce turbidity.

Method

The detailed procedure which has been in use at this laboratory for the past three months is as follows:

Reagents.—The same as those used in ordinary Kjeldahl determinations of organic nitrogen, with the addition of a 5 per cent. solution of potassium or sodium hydrate.

Procedure.—Fifty c.c. of the sample (or a greater or less amount, according to the nitrogen content) are digested with 5 c.c. of concentrated sulphuric acid, nitrogen free, and a small amount of copper sulphate until colorless. The digestion is completed by the addition of a few small crystals of permanganate to the hot acid. After cooling, the digestate is diluted to 250 c.c., mixed, and a portion (say 25 c.c.) is pipetted out, mixed with an equal portion of 5 per cent. sodium hydrate solution, and filtered through a filter paper which has been washed previously with 100 c.c. or so of ammonia free water to remove traces of ammonia. Twenty c.c. of the filtrate are pipetted into a Nessler tube, made up to 50 c.c. with best water, mixed by pouring from one tube to another, nesslerized, and read after ten minutes. A blank should be run on the entire process, and the result subtracted from the reading.

Discussion

This method has been in use in this laboratory for the past three months, and has given uniformly satisfactory results. In no case have we experienced any difficulty in getting a clear tube of the correct color to match the standards, even in tubes reading as high as seven or eight on the standards, corresponding to .07 and .08 mg. of nitrogen in the tube. In practice, however, readings of over five are discarded and new dilutions made, the rapidity of the process making it readily possible to introduce this desirable procedure.

In all these experiments, and in our regular work, the ordinary purified caustic soda in sticks has been used, preliminary purification having been found unnecessary.

Accuracy

Duplicate determinations made on the same digestate by distillation and by the direct method show a very close agreement. The following analyses were made, on three different dates, on sewages and effluents of trickling filters:

Total Kjeldahl Nitrogen

Parts per Million

Sample.	Distilled.	Direct.
Sewage	19.5	19.5
Sewage filtered	18.0	17.5
Sewage	20.0	19.5
Sewage filtered	18.0	18.0
Sewage	23.5	23.5
Sewage filtered	17.5	17.5
Effluent	15.0	15.0
Effluent filtered	9.5	9.0
Effluent	14.5	14.5
Effluent filtered	12.0	12.0
Effluent	13.5	Lost
Effluent filtered	12.5	12.5
Settled effluent	12.5	12.0
Settled effluent filtered	11.0	10.5
Settled effluent	12.0	11.5
Settled effluent filtered	11.5	11.0
Settled effluent	14.5	15.0
Settled effluent filtered	13.0	13.0

The uniformity of these figures shows the loss during filtration or by adsorption in the precipitate to be negligible.

This process commends itself for the following reasons:

(1) The great saving of time over the distillation process.

(2) The less bulky and bothersome apparatus required.

(3) An accuracy fully equal to that of the distillation method.

(4) The saving in time over all previously published direct methods, the immediate filtration taking the place of the long period of settling heretofore employed. The possible loss of ammonia in the filtration has been shown to be negligible.

(5) More satisfactory results locally than previously published direct methods, and greater probability of its being applicable under a wide range of conditions.

Summary

(1) The direct nesslerization of Kjeldahl digestates is greatly to be desired, but unless special precautions are taken such a procedure will result in a precipitation of the Nessler's reagent by certain constituents of the digestate.

(2) The present study indicates that under ordinary conditions no trouble will be experienced on account of calcium, no special treatment for its removal being necessary unless the calcium content of the sewage is greater than fifty times the nitrogen content.

(3) Magnesium, on the other hand, even in small amounts, will cause a turbidity in the tube and render a correct reading impossible.

(4) Magnesium can be satisfactorily removed, but to do this requires an excess of sodium hydrate equivalent to a concentration of 1.5 grams per 100 c.c.

(5) The excess of sodium hydrate necessary to remove the magnesium is not great enough to interfere with the reading. In fact, this reading is not appreciably affected unless the concentration of hydrate is such as itself to produce turbidity, or about 0.35 gram per 50 c.c. Nessler tube.

(6) It is not at all certain that the turbid tube results solely from the presence of magnesium. It has been determined, however, that under the conditions required for the removal of magnesium any other deleterious constituent is also eliminated.

(7) A process is recommended whereby all disturbing constituents can be removed and the Kjeldahl digestate nesslerized directly. By filtering the neutralized digestate a saving of several hours can be effected over heretofore proposed methods.

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RECENT RESULTS OF TERRESTRIAL MAGNETIC OBSERVATIONS

By L. A. BAUER

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In 1838 Sir Edward Sabine, who during the first half of the last century may justly be said to have taken the most active part in mapping out the distribution of the Earth's magnetic forces, concluded one of his reports with the following words: "Viewed in itself and its various relations,' the magnetism of the Earth cannot be counted less than one of the most important branches of the physical history of the planet we inhabit; and we may feel quite assured that the completion of our knowledge of its distribution on the surface of the Earth would be regarded by our contemporaries and by posterity as a fitting enterprise of a maritime people and a worthy achievement of a nation which has ever sought to rank foremost in every arduous and honorable undertaking." Lord Kelvin, then Sir William Thomson, said in his presidential address before the British Association meeting of 1871, referring to Sabine's conclusion of his magnetic labors as embodied in his magnetic charts of the world for the period 1840 to 1845: "Science will be provided with a key which must powerfully conduce to the ultimate opening up of one of the most refractory enigmas of cosmical physics, the cause of terrestrial magnetism."

Sabine says in another report, in 1854, after the discussion of the results of the magnetic observations made under his direction at the British Colonial Observatories during the period 1840 to 1850: "We have hitherto known magnetism only as a telluric force of much less apparent simplicity than gravity, and greatly requiring a key to enable us to apprehend its laws as well as its purposes in the general economy of nature. But if, as we appear to have reason to believe, we are to view the magnetism not only as *a telluric but also as a cosmical force,* the interest and importance of our inquiries regarding it must undoubtedly be viewed as greatly augmented."

If I may be permitted one more quotation, Maxwell, in his treatise on electricity and magnetism, remarks that "the field of investigation into which we are introduced by the study of terrestrial magnetism is as profound as it is extensive." "What cause," inquires he, "whether exterior to the Earth or in its inner depths, produces such enormous changes in the Earth's magnetism that its magnetic poles move slowly from one part of the globe to another? When we consider that the intensity of the magnetization of the great globe of the Earth is quite comparable with that which we produce with much difficulty in our steel magnets, these immense changes in so large a body force us to conclude that we are not yet acquainted with one of the most powerful agents in nature, the scene of whose activity lies in those inner depths of the Earth, to the knowledge of which we have so few means of access."

These four pertinent quotations will serve to point out admirably and briefly the main lines of research in terrestrial magnetism, viz.:

1. The distribution of the Earth's magnetism prevailing at any specified time, involving the mapping out of the so-called permanent magnetic field of the Earth.

2. The determination of the slow but steadily progressive changes of the Earth's magnetism, the so-called secular changes, requiring many centuries for their complete development. As the result of these changes, it is necessary to issue new magnetic charts, even for the practical purposes of navigation, at intervals certainly not over ten years apart, and preferably not over five years. It is this feature which differentiates the phenomena of the Earth's magnetism from those of other branches of geophysics. Thus, as Herschel aptly put it, "The tides and currents of the ocean—the general course of winds—the affections of climate, etc., remain for thousands of years appreciably constant, but a few years suffice to alter materially and the lapse of half a century or a century to remodel completely the Earth's magnetic forces."

3. The comparatively rapidly occurring variations and fluctuations of the Earth's magnetism, recorded usually by photographic means at magnetic observatories, such as the daily variation, the annual variation, magnetic perturbations, etc. It is by means of this class of magnetic phenomena that we are brought into sympathetic touch with influences coming to us both from the regions beyond the Earth as well as from the Earth's interior.

Manifestly, in the brief space of an hour it will be utterly impossible

to present completely the recent results of magnetic research along these three main lines of inquiry. Instead, we shall have to confine ourselves chiefly to the first two, and even here content ourselves with certain typical cases showing the general progress made.

In view of the establishment by the Carnegie Institution of Washington of a Department of Research in Terrestrial Magnetism, whose special function is to complete a general magnetic survey of the globe within a period of about fifteen years, this country at present occupies the same prominent position with reference to the problems of the distribution of the Earth's magnetism and its secular variation that England did in the last century during Sabine's time. However, even before this work of the Carnegie Institution was established, it was generally conceded that in no other country were these problems receiving the continuous attention paid to them in the United States. This was in not a little measure due to the fact that in our country, owing to the extensive use of the compass in land surveys, especially in the earlier ones, the investigation of these problems was of great practical importance, besides being of great theoretic interest.

Thus, almost at the very beginning of the work of the United States Coast and Geodetic Survey, it became necessary, on account of the numerous inquiries received from all parts of the country as to the direction of the compass needle and especially as to the changes which the compass direction had undergone during a certain interval of time, to include magnetic observations in its scope. So we find recorded for various places in the New England States determinations of the magnetic declination by the first superintendent, Hassler himself. And when Bache succeeded Hassler as superintendent, magnetic observations were definitely recognized as forming an integral part of the work of the Survey. Not only were determinations of the magnetic declination systematically undertaken at various places, but also the other two elements of magnetic measurements were included, viz., the dip of the magnetic needle and the intensity of the Earth's magnetic force. Bache had previously made a magnetic survey of Pennsylvania, in which enterprise he was not followed by other states until in quite recent years by the magnetic surveys of Missouri, New Jersey, Maryland, North Carolina, and Louisiana.

The magnetic survey of the United States thus fairly started under Bache was steadily prosecuted without interruption over the entire country and Alaska, under the main direction of the late chief of the

Computing Division, Charles A. Schott, whose exhaustive compilation and discussion of magnetic data for the determination of secular variation were unequaled by the work of any other magnetician during his period. Owing to the rather limited appropriations, however, it was not possible to make as rapid progress as was requisite to meet both practical and scientific needs. In the meanwhile, Professor William Bullock Clark, State Geologist of Maryland, perceiving the desirability of more rapid and more detailed work than could be undertaken with its funds by the Coast and Geodetic Survey, organized a magnetic survey of Maryland under my direction; this work was undertaken chiefly during the summers of 1896, 1897, and 1898.

It must be considered a fortunate circumstance for the development of magnetic research in this country that Dr. Henry S. Pritchett was at this time the superintendent of the Coast and Geodetic Survey. He was quick to perceive that the methods and plan of work followed in the Maryland survey could profitably be extended to embrace the entire country, and so he undertook a complete reorganization of the magnetic survey of the United States, creating a special division known as the "Division of Terrestrial Magnetism," the magnetic work previously, as above stated, having been under the charge of the chief of the Computing Division. At his request I prepared a plan according to which a magnetic survey of the United States might be undertaken in such a way that a general magnetic survey would be completed within a period of about ten years, after which the further work would consist in filling in details where local disturbances manifested themselves and in repeating observations at certain well-selected stations at intervals of about five years, with the aid of which a control would be had upon the secular changes, making it thus possible always to keep magnetic maps up to date. This plan called for an annual expenditure for field expenses of the magnetic survey and the magnetic observatories established in connection therewith of $25,000—about ten times the previous annual appropriations.

Dr. Pritchett, having succeeded in securing from Congress the increased appropriation, invited me to take charge of the work. Beginning, therefore, with July 1, 1899, a magnetic survey of the United States was prosecuted with means sufficient to occupy annually about four hundred stations, at which the three magnetic elements, declination, dip, and intensity, were determined, and to establish magnetic observatories, at present five in number, where the Earth's magnetic vari-

ations are being continuously recorded. These observatories are situated at Cheltenham, Maryland, the principal observatory, at Porto Rico, Baldwin, Kansas, Sitka, Alaska, and near Honolulu, Hawaiian Islands.

Furthermore, in 1903 another desire of Dr. Pritchett's was realized through the zealous interest of his successor as superintendent, Mr. O. H. Tittmann, viz., the incorporation of magnetic work at sea as one of the regular duties of the vessels of the survey in their passages between United States ports, thus securing magnetic data—and again the three elements—on the oceans bordering upon our coasts. Having secured the necessary instruments, I accompanied the Coast Survey steamer *Blake*, under the command of Mr. R. L. Faris, my successor in charge of the magnetic work of the Coast and Geodetic Survey, on her cruise from Baltimore to Porto Rico. Our work was so successful that upon arrival at San Juan we were enabled to cable Superintendent Tittmann, "Marine magnetics successful; observations secured daily." After the preliminary work on the *Blake*, other vessels were fitted out with magnetic instruments, viz., the *Bache*, the *Patterson*, and the *Explorer*, so that now the annual summaries of magnetic results also regularly include some obtained at sea, besides those on land.

These, in brief, are the general lines along which the expansion in the magnetic work of the Coast and Geodetic Survey was made in 1899.

Our first slide exhibits the status of the magnetic survey of the United States from the beginning—about 1840—up to June 30, 1899, hence up to the reorganization. The round dots represent the points of observation at which in general the three magnetic elements had been observed and at which, in a number of cases, these observations had been repeated at various intervals, beginning with about 1840. It will be seen that the work was mainly in the states bordering our coasts, the stations in the inland states being necessarily comparatively few in number and designed primarily as "repeat" stations for determining the secular changes over the entire country.

The next slide shows the status of the magnetic survey up to December 31, 1906, *i. e.*, up to about the time of my relinquishment of the charge of the work in order to devote myself to the still greater task—a magnetic survey of the globe. From this slide will be seen the large expansion that resulted within the period of seven years, 1899 to 1906. We now find every state fairly well covered, there being on the average one station to about 800 square miles, *i. e.*, in general there are values of the three magnetic elements at intervals of about 30 miles,

or, say, about one station per county in each state. This makes about 3,500 fairly uniformly distributed points over the United States at which the magnetic declination, the magnetic dip, and the intensity of the Earth's magnetic force have been determined by approved methods and with instruments carefully intercompared and standardized. In consequence it may be said that, considering the area involved—nearly equal to that of Europe, or about one-sixteenth of the entire land area of the globe—the United States of North America possesses the most complete and homogeneous magnetic survey of any country, and that the phenomena of secular variation have received more careful attention here than in any other country. While some of the European countries possess magnetic surveys of greater detail, with a much denser distribution of stations—as, for example, that of Great Britain, one station to every 139 square miles, and that of Holland, one station to about every 40 square miles—these surveys, having been undertaken with funds specially provided by certain organizations and not in general conducted under official or governmental auspices, could not be as systematically and continuously prosecuted as is the case with our own magnetic survey; they hence, necessarily, relate to various epochs. In the course of time we may hope to reach a density of distribution equal to that of certain European countries. In this connection it will not be amiss to point out that for certain regions of the United States this desired goal has already been reached, *e. g.*, the magnetic survey of Maryland embraced on the average one station to 100 square miles—hence occupying an intermediate position between those of Holland and Great Britain. Before passing to the next slide permit me to call your attention to the oceanic stations at which the magnetic elements have been determined in recent years by the vessels of the Coast and Geodetic Survey, as has already been stated.

Now to exhibit some of the results of this magnetic survey work. On the next slide we have shown us the lines of equal magnetic declination for the year 1902. In the construction of this chart it was necessary, owing to the insufficiency of the data when its construction was undertaken (about 1901), to make use of results obtained from other than governmental sources. The auxiliary data, consisting almost entirely of surveyors' results, did not, in general, possess the requisite degree of accuracy to permit full reliance being put upon them, making it hence unwise to do more than to draw general or regular lines of equal magnetic declination. Wherever, therefore, such regular lines appear in

the present slide, it may be safely concluded that the data were either not sufficiently numerous or not sufficiently reliable to warrant showing irregularities.

In the following slide (Fig. 1) a considerably different appearance is presented. Here we have the lines of equal magnetic declination for January 1, 1905, as based upon all the reliable magnetic observations secured up to about August 1, 1906, cutting out this time entirely sur-

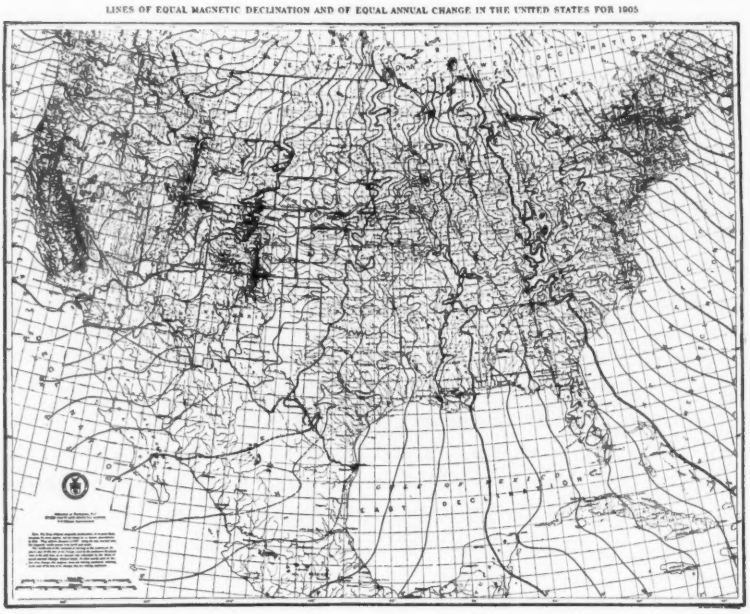


FIG. 1.—LINES OF EQUAL MAGNETIC DECLINATION AND OF EQUAL ANNUAL CHANGE IN THE UNITED STATES FOR JANUARY 1, 1905

veyors' data, the number and distribution of the reliable observations making this for the first time possible. In round numbers, as already said, the present chart depends upon the magnetic observations at about 3,500 fairly uniformly distributed points. What will impress one most, doubtless, is the exceedingly large number of twists and turns shown by the lines. In this respect the present chart differs materially from all previous ones issued for this country. We no longer have gracefully flowing or mathematical curves (as shown, for example, by the isogonic charts of forty years ago), but instead exceedingly irregular ones. This

is a sufficient proof that the present chart represents more closely the actual facts of nature than any previous one, for it is a well-known fact that the more numerous the reliable observations are, the more devious become the lines of equal magnetic values. In fact, we are being taught more and more that the irregularities are not the *abnormal* features, but, on the contrary, are the *normal* ones.

Regularities in the distribution of the Earth's magnetism over land areas do not appear to exist, at least not for any extended areas. Thus for states in which, judging merely from the superficial geological formations, no great irregularities in the magnetic distribution should occur, there they nevertheless do manifest themselves. The time will not permit going into all of these details and pointing out the precise relationship between local magnetic disturbances and certain physiographic or geological features. I can only point out a few typical cases. The agonic line, or the line of no magnetic declination, along which the compass needle points "true to the North Pole," is one of interest in its passage through the states. It will be noticed that it passes through Ohio somewhat to the west of Columbus and through Columbia, South Carolina. Hence, Columbus, Ohio, and Columbia, South Carolina, will serve to fix in our minds the approximate direction of this line at the present time.

From the figure it will also be seen that for the first time it was possible to project the lines over the oceanic areas immediately beyond our coasts. Here, as is to be expected, the lines appear more regular. Furthermore, with the addition of data acquired by the Carnegie Institution in Canada and Mexico since the construction of this chart, it has become possible in a forthcoming second edition embracing all data up to January 1, 1907, to extend the lines up to the forty-ninth parallel across the entire continent, as also to perfect the lines over Mexico, which had to be drawn more or less tentatively, owing to the paucity of the available material. There are likewise in preparation similar charts of the lines of equal magnetic dip and of equal intensity. When these have been completed, it will be worth while to undertake an analysis of the irregularities shown in the distribution and their correlation with geological formations, etc.

Not only, however, does the present chart represent a vast improvement upon our previous one, but also our knowledge of the secular changes has reached a stage of perfection not hitherto attained. Owing to some marked peculiarities exhibited by this phenomenon during recent

years in the United States, on account of which it was found unsafe to make predictions of the probable direction of the compass at various places for even such a comparatively brief period as five years, it became urgent to repeat the observations at more points throughout the United States and at closer intervals than was heretofore believed necessary. Thus, for example, in California the indications about 1885 were, that the compass, which pointed east of north, had reached its maximum easterly value, so that shortly thereafter it would begin to diminish, somewhat slowly at first and then at an increased rate. On the contrary, however, all recent observations have proven that easterly declination, instead of *decreasing*, since about 1890 has steadily *increased*. The present rate of increase is about 3′.5 per year, or 1° in about seventeen years. So again in Louisiana, where this reversal of the secular change was first detected, it was believed until but a few years ago that east declination was diminishing; instead, however, it was found that it had been steadily increasing for some time. It would appear as though the maximum which it was thought occurred in California between 1880 and 1890 was not a principal one, but a secondary one.

On the other hand, in most of the Atlantic States where we have west declination the values are likewise increasing, the annual rate of increase at present being for Massachusetts about 3′ to 3′.5. The present indications are that before many decades west declination will pass through a maximum in the New England States. This phase, according to recent observations by the Carnegie Institution, having already set in in Labrador and Newfoundland, is steadily moving southwestward. Possibly the briefest statement will be that given on the chart itself, viz., that, owing to the secular change of the Earth's magnetism, "the north end of the compass is moving at present to the westward for all places east of the line of no annual change, and to the eastward for places west of said line, *i. e.*, east of the line of no change the isogonic lines are moving westward, whereas to the west of this line they are moving eastward."

Since the line of no annual change does not coincide with the agonic line, we must distinguish three regions of secular changes in the United States. (1) In the region east of the agonic line or the line of no magnetic declination, where west declination prevails throughout, the declination is increasing from about 2′ to 4′ per annum, the amount in general increasing with the distance from the agonic line until the New England States are reached, where the maximum change

occurs; thence progressing farther northeastward the annual change decreases until we approach the region, before indicated, where west declination is passing through the maximum westerly value.

(2) In the region between the agonic line and the line of no annual change, passing, as will be seen, through Minnesota and Alabama in a direction practically parallel to the agonic line, the magnetic declination (east throughout this region) is decreasing at the rate of 0 to 2′ per annum.

(3) Finally, in the region west of the line of no annual change, embracing over two-thirds of the United States, the magnetic declination, being east throughout, is increasing at the rate of 0 to 4′ per annum, the maximum value being along the Pacific coast.

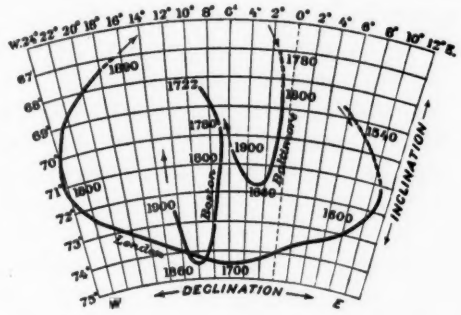


FIG. 2.—CURVES SHOWING SECULAR CHANGE IN MAGNETIC DECLINATION AND DIP AT LONDON, BOSTON AND BALTIMORE

We have indications that in the southern part of Mexico and Central America east declination is decreasing, whereas in the northern part of Mexico it is increasing. In Porto Rico, west declination is increasing at about 7′ per annum, or 1° in nine years.

The effect of the present secular changes in the United States whereby, as we have seen, the isogonic lines are being shifted from both coasts towards some line passing through Minnesota and Alabama—the line of no annual change—considered along with the equally well-known changes in dip and intensity, implies that the magnetic North Pole has moved during the past twenty years mainly southward and somewhat westward, the latter component of motion, however, being greatly subordinate to the southerly one.

In the next slide (Fig. 2) curves are exhibited which show the

secular changes both in the magnetic declination and in the dip at London, Boston, and Baltimore. These are the curves which would be described by the north end of a magnetic needle so suspended as to respond not only to changes in the magnetic declination, but also in the magnetic dip; the observer watching the movement is supposed to be standing at the center of suspension and looking towards the north end. This diagram serves to illustrate several of the interesting and at the same time most perplexing phenomena exhibited by the secular variation. In the first place, a glance suffices to show that, while the three curves are drawn to the same scale, the areas embraced by Boston and Baltimore are considerably smaller than that of the London curve. In England the secular changes of the compass needle can be followed from about 1540 to the present time, or over three and one-half centuries; this is, in fact, one of the longest periods in which these changes can be followed. It is seen that even here the curve is not yet closed and it is an interesting question whether it will close in a simple manner or whether before doing so it will not pass through a loop somewhat comparable with the curves shown by Boston and Baltimore—there being, in fact, indications of such loops—or whether, indeed, it will ever close exactly. In my own opinion, as based upon a variety of investigations, no exact closure will ever take place, that is to say, a freely suspended needle will doubtless never reoccupy in space the same position assumed at some previous epoch.

It is seen that the London curve passed through a period of maximum east declination of about 11° towards the end of the sixteenth century; that the compass pointed duly north and south about 1660; next, the dip had a maximum value of about 74°.5 in 1700, after which it steadily decreased, this decrease still continuing. The compass passed through another maximum, this time of west declination, somewhat over 24°, in the early part of the nineteenth century. Thus during the interval of about 1580 to 1820 the compass direction at London changed from 11° east to 24° west, or 35° in 240 years. Investigations have shown it would be rash to assume that this interval from turning point to turning point is one-half of the total secular variation period. In this country the intervals between two turning points are considerably less than that shown by the London curve, approximately, on the average, about one-half. Again the changes in the magnetic declination, as thus far witnessed in this country during the past two centuries, are considerably less than those experienced at London. In passing, permit me to

call your attention to a matter of historical interest as shown by the Boston curve, which, as is seen, begins about 1722. For this place, namely, we have the earliest value of the magnetic dip in this country, though values of the magnetic declination reach back to the early part of the seventeenth century. This value of the dip at Boston was due to the enterprise of William Whiston, who is chiefly known for his translation of Josephus. Whiston was anxious to capture the prize offered by the British Parliament for the discovery of an easy method for determining the longitude at sea, and believing that this problem could be solved by means of magnetic observations, especially of dip, he supplied various captains of vessels with dip circles. And thus it happened that Captain Othniel Beal made the first determination of the magnetic dip at Boston. Whiston himself made a large number of dip observations as well as of relative intensity in the southern part of England, this work constituting, in fact, the earliest land magnetic survey.

It will be noted that all three curves progress throughout their course in a clockwise direction, and this fact has been found to prevail in general over the entire Earth. Dr. van Bemmelen, with the aid of carefully compiled observations as obtained from the log-books of early voyages, found that the magnetic North Pole during the past three centuries has followed a similar course.

And while speaking of the magnetic North Pole, let us not forget Amundsen's great achievement. Amundsen is at present about thirty-five years of age and extremely modest as to what he has accomplished. You will doubtless recall that the first determination of the position of this pole was made by Captain James Clark Ross, who in June, 1831, found that on Boothia Felix, in latitude 70° 5′.3 north and in longitude 96° 45′.8 west of Greenwich, the dip of the magnetic needle was 89° 59′.5. Now the chief merit of Amundsen's work is not simply that he has found the point again where the dip needle stands practically vertical, but that he made a complete magnetic survey of the entire region involved, and furthermore operated self-registering magnetic instruments in a nonmagnetic hut for a period of nearly two years. It will thus be possible to determine more precisely than was done by Ross the exact position of the Pole and to eliminate the possibility that any one point where the dip needle was observed standing vertical might be locally disturbed. There are, in fact, a number of points on the Earth where, owing to local disturbances, the dip needle stands vertical, the compass direction converges from all sides, and where the force acting upon the

same practically vanishes. Thus, for example, I found such a point, in the fall of 1900, on Douglass Island, near Juneau, Alaska, the local attraction resulting from this local magnetic pole being sufficient to affect compasses on board vessels passing through the Gastineaux Channel, a mile and one-half from shore by about a point (11°). In Southern Russia exists a similar place, where the vertical magnetic force is even greater than at the true North Magnetic Pole.

From the magnetic survey of the United States, we are led naturally to a consideration of the magnetic survey of contiguous territory, viz., that of the Pacific Ocean, now in progress under the auspices of the Carnegie Institution of Washington. An exhaustive discussion of all the magnetic data at present available from over the entire Earth showed that no material progress could be expected in the solution of some of the greater problems of the Earth's magnetism, such, for example, as were referred to in the quotations at the beginning of this paper, until we possess a magnetic survey of the globe which will not only embrace the land areas but the ocean areas as well, and will be based upon strictly homogeneous material throughout. A complete and unequivocal solution of the problem of the precise distribution of the Earth's magnetism requires, furthermore, observations in the vertical direction—in ocean depths and in atmospheric regions.

Thus it was found that in spite of the large amount of most admirable magnetic work done during the latter half of the past century by various eminent investigators, this work was practically all confined to the land areas, and since the land area is exceeded nearly three times by the oceanic area, and since, furthermore, as we have already seen in the case of the United States, the land observations are almost invariably "disturbed," it can readily be seen that deductions applying to the entire Earth, based practically upon land data, are more or less unsafe. As far as the determination of the general magnetic constants and of the general facts as pertaining to the magnetism of the entire Earth, no material advance was made during the period stated. Thus the magnetic maps for the period of about 1880 or 1885 represented no very great improvement over those of Sabine of 1840 to 1845, owing chiefly to the lack of data on the oceans. In certain regions, owing to defective knowledge of secular changes, the later maps were not even as good as the earlier ones. This will be made clear by the next slide, which shows the condition of oceanic magnetic work up to the time of the

work of the Carnegie Institution. Thus, *e. g.*, practically all of the work in the southern oceans was done during the period of the Sabine charts by the expeditions of the *Erebus, Terror,* and *Pagoda,* these vessels being the first ones fully equipped with magnetic instruments permitting the determination of the three elements, magnetic declination, dip, and intensity. It is only recently, *i. e.*, since the appearance of the latest magnetic charts of the last century, that additional material in these regions was obtained by the various Antarctic expeditions.

The *Novara,* an Austrian frigate, obtained a series of declination observations in 1857-1860 which were likewise available to Sabine when he constructed his charts.

The next expeditions equipped for general oceanic magnetic work were those of the *Challenger,* 1872 to 1876, and the *Gazelle* (a German vessel), 1874 to 1876. For the Pacific Ocean it will be noted that the *Challenger* obtained magnetic observations along but a single line passing from Valparaiso to Tahiti, the Hawaiian Islands, and Yokohama. The present magnetic maps for this part of the Earth have had to be based, therefore, almost entirely upon the observations obtained along this one line—brought up to date, furthermore, with more or less conjectural values of the secular changes—upon the observations made on islands and coasts (both of which are in general magnetically disturbed), and upon those obtained occasionally from vessels.

It will be seen that for the eastern part of the Atlantic Ocean the available material is more abundant, especially owing to the acquisitions from the recent Antarctic expeditions.

Passing to our own coasts, it will be seen that the vessels of the Coast and Geodetic Survey since 1903 have already contributed materially to our information.

In 1905 the Department of Research in Terrestrial Magnetism of the Carnegie Institution of Washington was authorized to undertake a magnetic survey of the Pacific Ocean, and the necessary funds were allotted. After considerable advertisement, the brig *Galilee,* a wooden sailing vessel of about 600 tons, built in 1891 and engaged in freighting in the Pacific Ocean, was chartered for the purpose. The principal changes required to adapt her to the work to be undertaken were the substitution of the steel rigging by hemp, the replacing as far as possible of the iron in the blocks and tackle by nonmagnetic metal, and the building of a special observing bridge running fore and aft between the masts and about 15 feet above the deck. The instruments mounted

on this bridge were on the average about 25 to 30 feet from the remaining masses of iron, consisting chiefly of the iron bolts in the sides of the vessel.

While, then, it was not possible to convert this vessel completely into a nonmagnetic one, as would have been desirable, the changes made resulted in reducing the corrections due to the disturbing influence of the iron to such an extent that the so-called ship's "magnetic constants" turned out to be smaller for this vessel, on the average, than those of

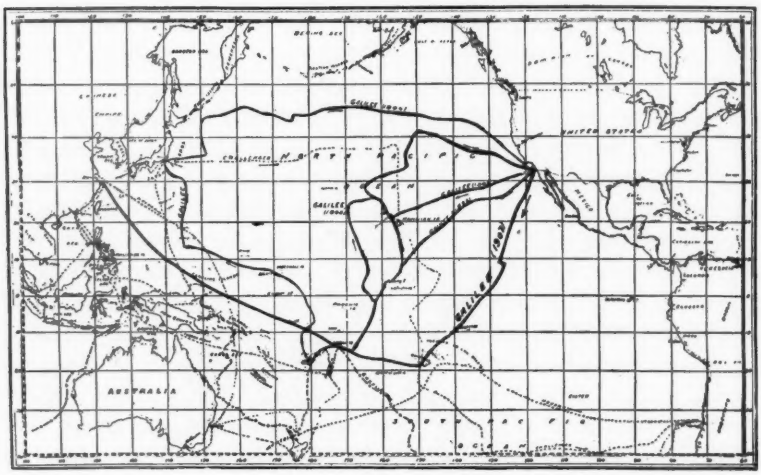


FIG. 3.—MAP OF PACIFIC OCEAN SHOWING ROUTES TRAVERSED BY EXPEDITIONS DESIGNED TO SECURE MAGNETIC DATA

Challenger, 1872–1876 .....
Novara, 1857–1860 × × × × ×
Gazelle, 1874–1876 — + — + —
Galilee, Aug. 1, 1905–May 8, 1907 ———

any vessel thus far engaged in oceanic magnetic work. However, the corrections are still large enough so that they require to be taken into account to satisfy the requirements of the problem. These corrections must be determined by special observations, consisting of swinging ship in port and at sea as often as circumstances will permit, which necessarily cause more or less delay in both the field and office work. Unfortunately, experience during the past two years has also repeatedly shown that these corrections do not strictly follow the laws prescribed by the mathematical analysis of the deviations.

Namely, the corrections arise chiefly from the magnetic induction in the soft iron parts of the vessel, and hence are subject to various

accidental conditions, such as length of time pursued by the vessel along any one course, or the amount of buffeting the vessel has been exposed to from the waves, etc. Accordingly, it would be more economical all around, were it possible, to secure an entirely nonmagnetic, specially built vessel. The construction of such a vessel presents no mechanically insurmountable difficulties. It seems a pity that in the very regions where the disturbances due to local magnetic masses are a minimum we should introduce an extraneous source of disturbance by not having an entirely nonmagnetic vessel.

However, conditions did not permit our waiting for such a desired vessel, and the attempt was accordingly made to secure magnetic data as accurately as possible and to solve the problem given to the Committee on Terrestrial Magnetism of the International Association of Academies in 1904, upon the proposal of the late Professor von Bezold, viz., "The determination of the best methods of making accurate magnetic observations at sea."

The following slide (Fig. 3) shows the progress already made in the Pacific Ocean by the magnetic survey yacht *Galilee* up to the end of her second cruise last year. Furthermore, up to date during her present and third cruise she has followed a line from San Diego to Tahiti and the Samoan Islands, and is now on her way to Yap of the Caroline Islands and to Shanghai.[1] From the latter port she will proceed to Midway Island, thence to Sitka, and from there to Honolulu, where it is hoped she will arrive in time to undertake another short cruise before the end of the present year, embracing the region between Easter Island and the Marquesas Islands. As a vessel of the Coast and Geodetic Survey, the *Explorer,* is now *en route* from Baltimore to San Francisco via Cape Horn, and is equipped with the necessary instruments for the determination of the three magnetic elements in the region of the Pacific Ocean bordering upon the west coast of South America, Central America, and Mexico, the end of the present year will witness the completion of a general magnetic survey of the North Pacific Ocean, inclusive of a large portion of the South Pacific Ocean, making it possible to construct more accurate magnetic maps for this region than hitherto available.

Several slides were exhibited of the vessel *Galilee,* showing instruments used, methods of observation employed, and specimen results obtained. The general endeavor is to obtain two entirely independent

[1] The vessel arrived at this port on May 8.

determinations of each magnetic element, declination, dip, and intensity, at different parts of the observing bridge, so as to vary the magnitude and sign of the deviation corrections.

It has been found that declinations and dips can be determined at sea with an absolute accuracy of 5′ to 10′, horizontal intensity to within $\frac{1}{800}$ to $\frac{1}{500}$ part of its value, the precise accuracy depending largely upon the extent of the observations. The principal difficulty in securing results, especially of declination, does not arise from the motions of the ship, but from purely meteorological causes preventing the securing of the necessary solar or stellar observations. Improvement in the present azimuth devices for ocean work is the chief problem remaining.

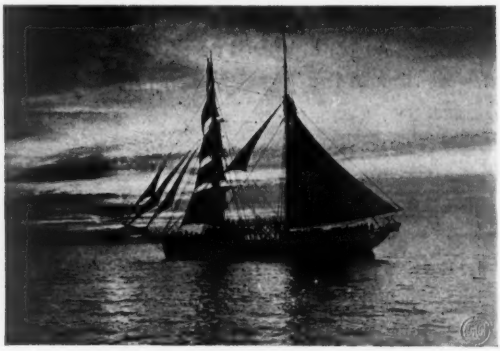


FIG. 4.—THE "GALILEE" LEAVING SAN DIEGO, CAL., ON HER THIRD CRUISE, DECEMBER 22, 1906, UNDER THE COMMAND OF MR. W. J. PETERS

A comparison of the results of the *Galilee* with those scaled from the most recent magnetic charts shows that the latter give systematically too low declinations between San Francisco and Honolulu by about 1° to 2°, these amounts being exceeded in other parts of the North Pacific Ocean; furthermore, the chart values of the dip are, in general, too small by about 1° to 3°; and the values of the horizontal intensity too high by about $\frac{1}{250}$ part.

In conclusion, some specimen results of extremely interesting fluctuations registered by magnetographs at various magnetic observatories were shown by slides, *e. g.*, effects recorded simultaneously over the entire Earth in connection with the Mt. Pelée eruption of May 8, 1902, as also certain effects recorded in connection with the San Francisco earthquake.

SPEED REGULATION OF HIGH HEAD WATER WHEELS

By H. E. WARREN

Read January 10, 1907

EVERY one knows that most streams, if traced from the ocean back to their origin, change in character, from a great mass moving at slow velocity in a single channel, to a number of tributaries, each consisting of a fraction of the mass, but with greater and greater average velocity of flow as the mountainous sources are approached.

Since any mass in motion contains energy proportional to the square of its velocity, it is apparent that the power of a stream per mile of length may easily be greatest where the actual amount of water flowing is comparatively small, and indeed it would appear to be generally true that the total power per mile of the combined tributaries would be much greater near the mountainous sources than near the sea.

Partly because the foregoing facts were not appreciated until recent times, partly because the works and habitations of man have been confined to low and approximately level places, partly because no efficient devices had been invented to transform the energy of rapidly flowing water, and principally because there was no means of transmitting energy to a distant place, the utilization of mountainous water powers is of recent growth. For the reasons just stated, it is evident that power development near the sources of streams, or any other place where the fall, by which is meant the change in level, is very rapid, is a very different proposition from that where the fall is gradual and the quantity flowing great.

Considering these two problems, we may point out the characteristics of each as follows: In most places where low heads are available the country is comparatively level and the soil fertile; consequently such regions are populous and supplied with railroads. Generally, manufacturing has gravitated towards the streams for very many reasons. The mills, having been built mostly when trusts and monopolies were unknown, are generally small; therefore the power requirements are

readily met by erecting low dams and directing the flow of water through wheels situated in the factory buildings. Transmission from these wheels is by means of belting and shafting, which form a very large portion of the maximum load. Speed regulation is consequently a simple matter, because such a large part of the load is constant that the largest variations are not great proportionately. Moreover, with an enormous mass in pulleys and belting, the inertia is very great and tends strongly to steady the water wheels. The hydraulic problems are not generally complicated by long water columns or pressures difficult to control.

On the other hand, the utilization of water power where the fall is rapid involves not only the electrical transmission of energy to distant points, but also the construction of a very different type of water wheel, with special control mechanism, long pentstocks to convey the water under high pressure, speed-governing devices of extreme sensitiveness to take care of rapid variations in the electrical load, and water relief apparatus to prevent damage by pressure waves in the long supply pipes.

Considering in detail the special features which accompany the development of water power under high heads, it will appear that some are favorable, while others are the reverse. The fact that the spouting velocity of the water, which varies directly with the square root of the head, is much greater than in low head installations means that the peripheral velocity of the water wheels will be high, and for a similar type of turbine the angular velocity would, therefore, be higher than is usual in low head developments. High velocity of rotation means economy in electrical generators, of which the size and weight for equal output vary nearly inversely with the revolutions per minute. High velocity of rotation also implies great kinetic energy in the rotating parts, which is favorable for speed regulation. In most cases of extremely high head, however, it has been found expedient to make use heretofore of impulse wheels, which run at considerably slower angular speed than reaction turbines of the same capacity; therefore the gain in cost of generators and in kinetic energy of the moving parts is not so great as the increased spouting velocity of the water would indicate.

The great normal pressure of water in high head plants requires careful engineering foresight to prevent trouble. The more obvious effects, such as stress and deformation of the lower part of the pipe

line, with its valves and other connections, can be taken care of without great difficulty; but the control of the water as it rushes to the wheel is an exceedingly serious proposition. In low pressure turbines it is customary to regulate the quantity of water flowing to the wheel by simple gates of the well-known cylinder or wicket type. Entirely aside from the question of efficiency, it is found very difficult to use similar gates where the pressure is very great. Some of the reasons are that such gates are liable to be deformed and made to bind or rub; they then become tremendously out of balance, owing to uneven distribution of the pressure of the water, and they leak so fast when closed as to waste water and keep the wheels in motion continually. The foregoing statement is not an assumption, but is an illustration of what has actually happened in several moderately high head installations in this country where modifications of low head turbines have been used. But these objectionable features are not prohibitive, because governors are made powerful enough to move gates even though they are binding and out of balance, while leakage when the gates are closed may be checked by secondary gates in the pentstocks of the wheels, or the wheels may be brought to rest in spite of the leakage by powerful friction brakes.

High pressure, with its accompanying great velocity of flow, involves extremely difficult work for the designer and builder of reaction turbines. The water passages must be very small in proportion to the output, and yet the contour must be accurate. These small passages are easily clogged; therefore the water supply must be reasonably clear or else filters may be needed. Slight variations in the curvature of the passages are likely to produce very great variations in efficiency. The surfaces must be very smooth and free from abrupt changes of curvature, the material must be tough and homogeneous; otherwise erosion by the rushing water will quickly bring about destruction. The worst problem of all, perhaps, is the construction of a gate or gates which will perform the function of varying the output of the wheel at will, from zero to full load, without interfering with the efficiency of the turbine and which will move with reasonable freedom. The amount of work and thought which has been given towards solving these problems is enormous, for it has been obvious from the beginning that reaction turbines have fundamental advantages over other types of water wheels in lower cost per unit of power.

On account of the very great difficulties in designing and constructing reaction turbines for the utilization of high pressure water power,

there grew up many years ago in America, and to a lesser extent abroad, a strong tendency towards the nearly exclusive use of so-called impulse wheels wherever the head exceeded 100 or 200 feet. Such prime motors, which are also familiar to all under the name of tangen-

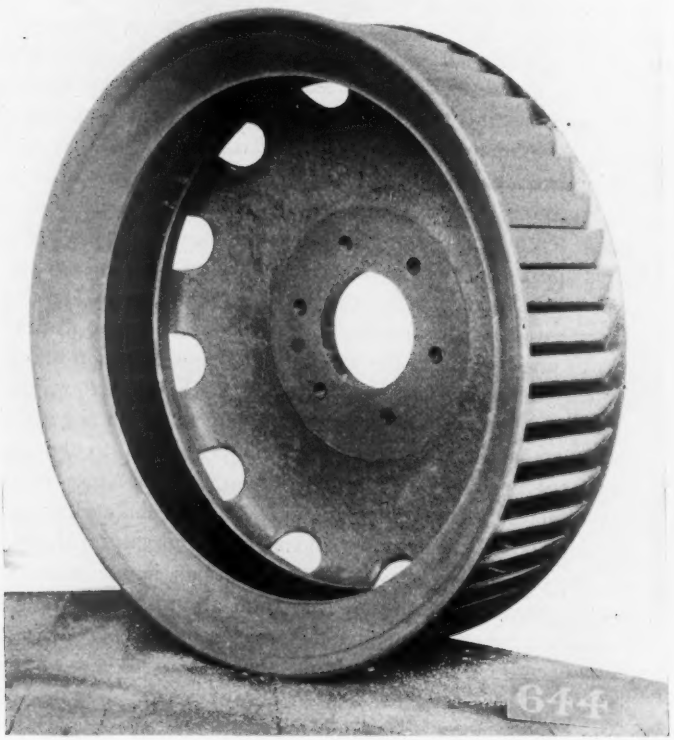


FIG. 1.—TYPE OF TURBINE WHEEL USED FOR HIGH HEADS
Entire circumference active when in operation

tial, or Pelton, wheels, are exceedingly simple. In their original form these resembled in principle and action the paddle wheel of an old-fashioned steamboat, made to rotate by the impact against its blades of a stream of water from a fireman's nozzle. Obviously, turning the nozzle towards or away from the vanes would vary the amount of

FIG. 2.—IMPULSE WHEEL DEVELOPING 5,000 HORSE POWER AT 865 FEET HEAD
Active portion consists of lower buckets

water striking them, and consequently the power of the wheel. If the stream were turned so as not to strike the blades, the wheel would come to rest. Evidently the force required to deflect the nozzle would be extremely slight because of the absence of friction or positive tendency to point in any particular direction. The evolution of the impulse wheel has not removed the essential features mentioned above. The vanes have been changed from flat projections to concave double buckets finely polished, and designed to take water which strikes them, and turn it outwards and backwards through an angle of almost 180°, without causing interference or excessive commotion. The nozzle has been supported on trunnions to take the reaction of the jet without interfering with its deflection, and the curvature of the inner surface has been altered by experiment until the stream which issues is so free from eddies as to resemble a glass rod. By these means the efficiency of the impulse wheel when utilizing the entire stream from its nozzle has been made as good as or better than that of the best reaction turbines. Unfortunately, however, the output per unit of weight must still remain at a great disadvantage as compared with a reaction turbine under the same conditions, for in the former the conversion of energy is confined to a very small portion of the rim of the wheel, while in the latter the entire surface is active. The disadvantage of the impulse wheel in output per unit of weight is sometimes lessened by allowing several jets to strike the buckets at different points on the circumference. In many cases the nozzles are fixed so as to direct their streams squarely against the buckets, and other simple means, such as hoods or shields, are provided to deflect a portion or the whole of the water.

The great waste of energy which takes place with an impulse wheel when a portion of the water is being deflected for the purpose of speed regulation has brought about the design of such wheels where the jet of water is not deflected at all, but instead the cross-section of the stream is altered by means of a needle valve in the nozzle. The construction is such that the stream flows through the annular space between the inner surface of the nozzle tip and a peculiar valve spindle, which looks somewhat like a beet with an elongated root, the two parts being held concentric by force of the flowing water. When these parts are properly designed the stream does not remain hollow, as might be expected, but converges to a solid cylinder of water a short distance from the nozzle. By moving the valve spindle back and forth axially, the width of the annular space through which the

water flows may be changed at will, and thus the efficiency of the wheel may be kept high throughout the entire range of output. The only important objection to this type of wheel is that an element of great danger is introduced by such sudden variations in the velocity of the water in the long pipe line which must invariably be used.

In order to get the benefit of safe and good speed regulation, impulse wheels of the very best type are now furnished with com-

FIG. 3. — STREAM ISSUING FROM NEEDLE-NOZZLE AT ENORMOUS VELOCITY TO DRIVE IMPULSE WHEEL

bination deflecting nozzles which have needle valves, the governors being designed to control the deflection, and some other means provided to produce slow movements of the needle valves. Ordinarily with this arrangement the needle valve which regulates the cross-section of the jet is adjusted from time to time by hand as the maximum load varies, so that the governor in order to maintain constant speed is obliged most of the time to direct the stream almost, but not quite, squarely against the moving buckets. If the load increases so that

the portion of the stream which is held in reserve by the governor is inadequate to maintain the speed during sudden peaks in the load curve, the cross-section of the jet is increased by an attendant.

By a device recently invented the need of an attendant to look after this detail may be eliminated. Instead, a small electric or water motor is mounted on the nozzle, so that it may move the needle valve in or out very slowly. Control contacts or valves for the motor are arranged to actuate it in a proper direction whenever the main nozzle is deflected away from a predetermined position by the governor. As a result, the cross-section of the jet will be maintained at a certain margin above that necessary to carry the average load. Such a device is better than

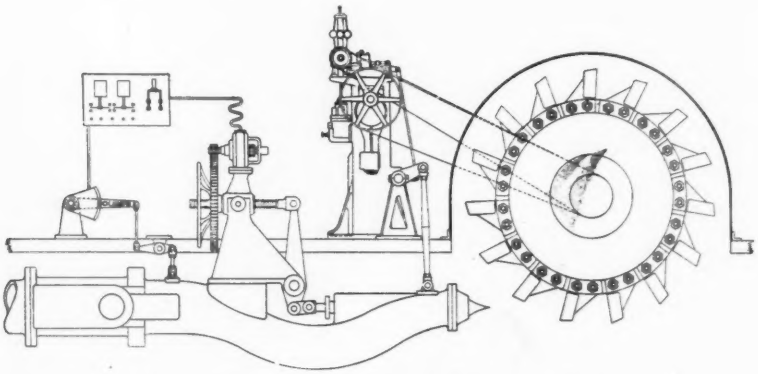


FIG. 4. — AUTOMATIC NEEDLE AND DEFLECTING NOZZLE

manual control because of its unceasing vigilance; it is just as safe because the fastest travel which it can give to the needle valve will not create water hammer; and it is obviously cheaper in operation.

The function of a governor in connection with a water wheel is to maintain the speed nearly constant. In order to do this it must be able to control the water acting upon the wheel; generally it must be able to exert great force. Since the load is liable to change rapidly, the governor must move quickly. Since the governor cannot act at all until the speed has departed from the normal, it is important that it should be exceedingly sensitive to slight speed variations and should begin to move as soon as they occur. Because the speed cannot return to its normal value as quickly as the governor moves, the machine must act and then wait for the speed to return. The governor ought to be

able to act when the water wheel is standing still; otherwise some other means must be used in starting.

The foregoing, which are essential features of a good governor, apply equally to high and low head water powers. A careful analysis will show qualifications which are conflicting and difficult to realize.

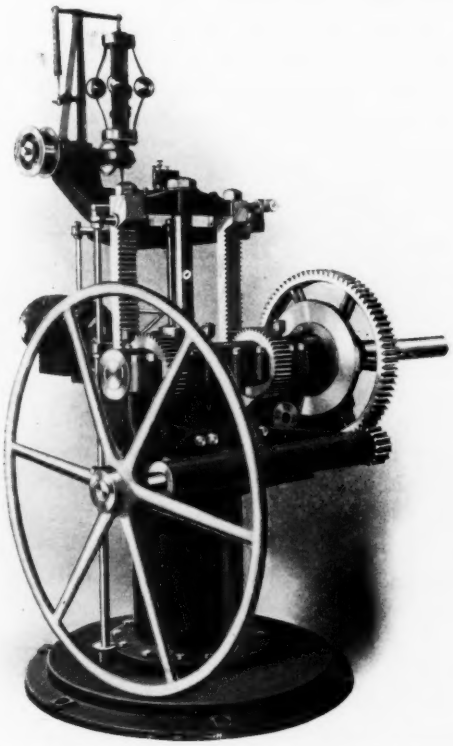


FIG. 5.—HYDRAULIC GOVERNOR, 30,000 FOOT POUNDS PER STROKE CAPACITY, USED WITH LARGE TURBINES

Yet hydraulic governors which are being manufactured today have them all and others in addition. As regards force exerted in action, governors are now in constant service which develop at their normal rating 50,000 pounds push at the piston rod; it is somewhat difficult to imagine a gate which would not budge when urged in such a manner. For speed of action the limit at present on small governors is some-

what less than one-half of one second for a complete stroke, which means that the governor can shut off or turn on the entire supply of water to the wheel within that interval. The largest governors have a maximum speed of from one to three seconds per stroke. Regarding sensitiveness, it is possible to make adjustment while the governor is in action. Variations within one-half of one per cent. cause prompt movements; in fact, it is not easy to measure the smallest variations which will be felt by the machine. The feature of waiting, after it has moved the gates a proper distance, for the speed to return is called anti-racing. This may not be expressed in units, but is quite satisfactory under actual conditions.

The speed regulation of high pressure impulse wheels with deflecting nozzles is the easiest problem in governor engineering. A small regulator developing from 2,500 foot pounds to 7,000 foot pounds is powerful enough for the largest units. This should be of the oil-pressure type. Such machines may be wholly self-contained. The connections between the governor and the nozzle are simple and inexpensive. The degree of speed regulation which can be obtained is about the same as with a steam engine.

The problem of getting the best possible speed regulation from a high pressure turbine or an impulse wheel with needle valve control needs very careful thought if, as is nearly always the case, either of these is located at the end of a long feeder pipe. The great difficulty is that a long column of water possesses so much inertia that its velocity cannot be changed with sufficient rapidity, and moreover the changes in rate of flow which actually occur introduce an element of great danger. A simple illustration will show why this is so. Imagine a turbine operating at the end of a feeder pipe 5,000 feet long. Assume a maximum rate of flow in the pipe of 8 feet per second, which is frequently exceeded. If the head were 400 feet and the pipe 5 feet in diameter this would correspond with an output of 5,600 horse power. In such a case the actual weight of water in the pipe would be slightly over 3,000 tons, which exceeds that of a loaded freight train half a mile long. Now 8 feet per second is five and one-half miles per hour, and it does not require very deep thought to see that it would be a rather difficult operation to start such a train from rest, bringing it to that speed within a second or two; it wouldn't be much easier by the use of the engine alone without brakes to bring such a train back to rest again in the same time interval. Yet this is just

what some engineers expect can be done to an equivalent water column. If the water and pipe were absolutely inelastic, it would be easy to calculate the average pressure in pounds per square inch which would be

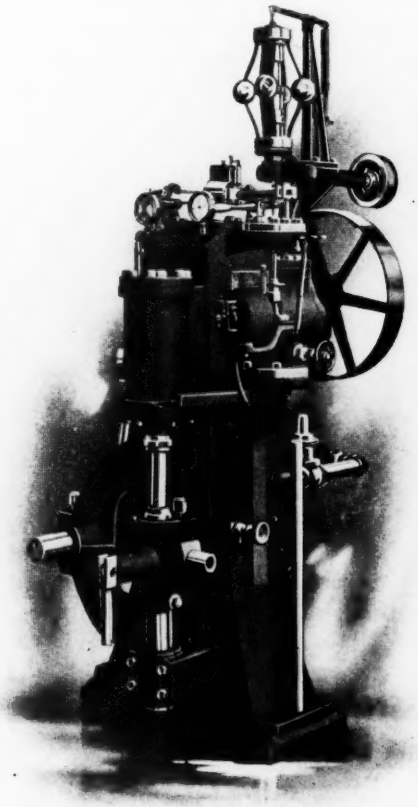


FIG. 6.— HYDRAULIC GOVERNOR, 2,500 FOOT POUNDS PER STROKE CAPACITY, USED WITH IMPULSE WHEELS

required to stop the moving water within, say, two seconds. This would be equal to about one-eighth of the weight of a column of water of 1 square inch section 5,000 feet long, because 8 feet acceleration in two seconds is approximately one-eighth as great as the acceleration due to the weight of a substance acting on its own mass. This amounts

to 271 pounds per square inch, while the static head is only 171 pounds per square inch. As a matter of fact, the pressure induced in stopping the moving water column by the action of a governor upon the gate of the turbine would greatly exceed this amount, because the retarding action would not be distributed uniformly over the two-second period. An exact solution of the problem is impossible because of the irregular movement of the turbine gate in combination with the uncertain elasticity of the water and pipe. While it is impossible to determine the actual initial rise of pressure caused by a sudden closing of the turbine gates, the matter is made even more complex by pressure waves, which, originating near the gate, travel back and forth through the water with the velocity of sound, setting the whole mass into vibration like an organ pipe. Because of these waves there are formed nodes and loops of pressure at various points in the length of the pipe, so that it may happen that the stress will be greatest near the middle.

The foregoing argument shows clearly the need of a relief valve wherever a feeder pipe is so long that dangerous pressures will be generated by the necessarily quick action of a governor. However, this solution is not so easy as it seems, on account of the part played by the pressure waves which run back and forth through the elastic water column. Any ordinary valve, such as is used for steam, would open and close so rapidly as to act like a reed upon an organ pipe, and thus maintain and increase the vibration of the mass. In order to be at all effective, a relief valve must be deadbeat; but it must also open quickly. Its time of closing must be long compared with the vibration pitch of the water column. This latter requirement is rather difficult with the exceedingly long pipe lines, which sometimes bring water several miles. It may be interesting to know that special valves are now built which will open instantly and consume several minutes in closing, the speed of action being, of course, adjustable.

Although it is possible to prevent excessive rise of pressure due to reduction in velocity of long water columns, no means have been devised to produce quick acceleration of the water when, because of a sudden increase in load, the speed of the turbine begins to fall. The governor will open the gates promptly, with the immediate result that the water pressure will drop, and also the already inadequate power of the water wheel; therefore the speed will fall still farther and the governor continue opening the gates until they are wide open. The reason why the pressure falls when the gates open is simply on account

of the inertia of the mass, which cannot keep pace with the demand for water. After a certain time interval, which may be several seconds,

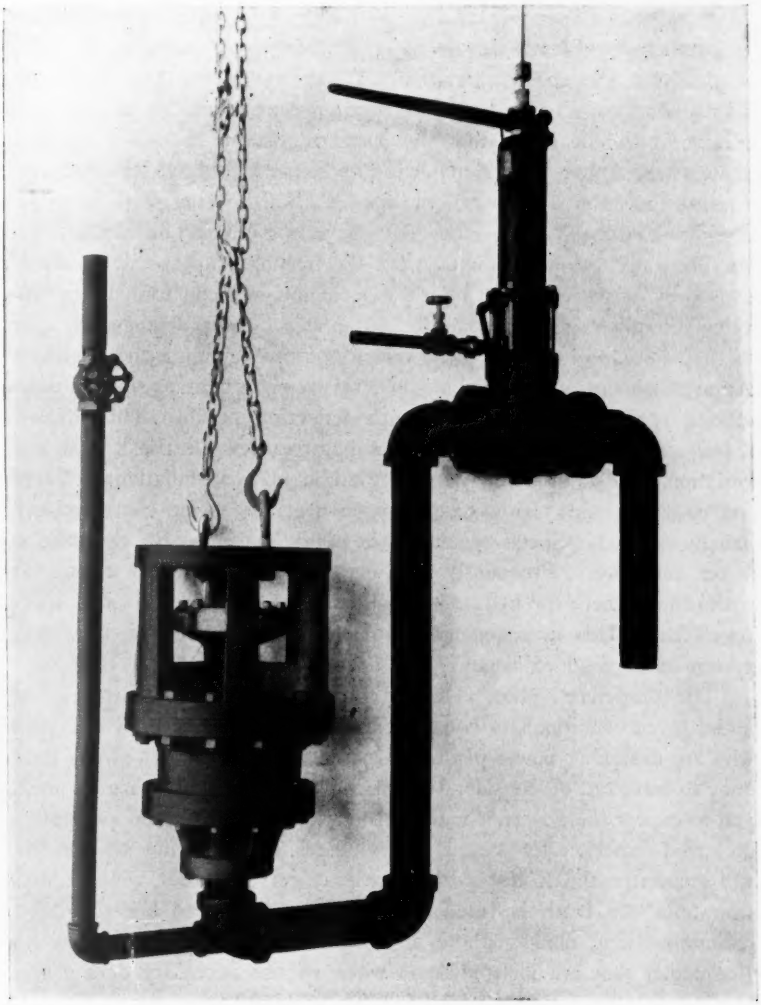


FIG. 7. — HYDRAULIC RELIEF VALVE

the water column will have accelerated sufficiently to supply what is needed by the turbine. By this time, however, the speed may be far

below normal. There will be a rapid acceleration of the water wheel, which will pass normal speed because of the excessive gate opening, and as a result the governor will close the gates quickly, causing the relief valves to operate. If the governor is not made very deadbeat and rather sluggish, this cycle of events will be repeated to the great detriment of the speed regulation. When the governor is made sufficiently deadbeat so as not to encourage pressure oscillation of the water column, it will be found that the speed regulation is poor if the load changes are large and sudden; it is impossible for this to be otherwise, because the water column cannot possibly alter the energy given to the wheel fast enough, whether the gates be in one position or another.

The only complete remedy for the troubles in speed regulation caused by excessive inertia of a water column is some form of by-pass valve directly connected with the water wheel gates, arranged to open as they close, and thus keep the velocity of the column nearly constant. An arrangement of this kind is substantially equivalent, as regards water efficiency, to an impulse wheel with deflecting nozzle. This involves a frequent waste of water equal to that required for the largest load variations, and cannot well be permitted in many installations. Therefore in such power plants as have been described some compromise is usually reached. Speed regulation is partly sacrificed for the sake of water economy. Frequently such stations are connected electrically with others where the hydraulic conditions are favorable to good speed regulation. This arrangement ensures the even speed of the whole system with good efficiency.

The predetermination of speed regulation, which can be obtained under given conditions, is considered of great importance by engineers who are designing power plants. Unfortunately, there is a strong tendency to leave out of consideration the physical laws which are involved, and to expect the governor manufacturer to furnish a certain percentage of speed variation for stated load changes. A governor builder who will guarantee the lowest percentage may get the order, while another who tells the truth is ruled out. These guarantees are sometimes ludicrous, being made without any regard to mathematics or physics. Frequently they are insisted upon when all the necessary data cannot be obtained; at such times the instinct of a weather clerk is the best guide. Conditions are improving, however, and very frequently nowadays sufficient information is supplied so that an accurate prediction can be made. The following is submitted as a comparatively simple analysis of the problem of predetermining speed regulation:

Let S = normal speed in revolutions per minute.
S_1 = speed in revolutions per minute after load change.
K = kinetic energy in foot pounds of revolving parts at speed S.
K_1 = kinetic energy in foot pounds of revolving parts at speed S_1.
$I = \int wr^2$ = moment of inertia or fly wheel effect of revolving parts.
L, L_1 = loads in horse power before and after a change.
p = the horse power output from the water wheel corresponding to L.
p_1 = the horse power output from the water wheel corresponding to L_1.
HP = the full-load horse power output from the water wheel.
$\Delta K = K - K_1$ = the excess energy output from the wheel in foot pounds while the governor is adjusting for a change in load from L to L_1.
$\Delta S = S - S_1$ = temporary change in speed.
δ = percentage temporary change in speed.
g = the acceleration due to gravity = 32.2 feet per second.
T = the time required for the governor to make a stroke.

According to the laws of physics, $K = \frac{I 2\pi^2 S^2}{g 60^2}$; (1)

simplifying, $K = .000170\, IS^2$. (2)

As long as the output from the wheel is equal to the load, the speed S and kinetic energy K of the revolving parts will remain constant. The governor is designed to adjust the output of the wheel to correspond with the load, but it cannot do this instantaneously. Consequently, during the time T required to make the adjustment of the control mechanism after a load change there will be a production of energy by the water wheel greater or less than the load. The entire excess or deficiency will be added to or subtracted from the kinetic energy of the revolving parts, and will become manifest by a corresponding change in speed.

Neglecting friction losses, and assuming that the power of the water wheel is proportional to the percentage of the governor stroke and that the movement of the governor after a load change is at a uniform rate, the excess or deficient energy which goes to or comes from the revolving parts after an instantaneous change of load from L to L_1

is measured by the average difference between the power of the wheel and the new load during the time T while the governor is moving, multiplied by T.

Expressed in foot pounds, $$\Delta K = \frac{p - p_1}{2} T \times 550. \tag{3}$$

This produces a percentage change in the kinetic energy of the revolving parts of

$$\frac{100\Delta K}{K} = \frac{100(p - p_1)T \times 550}{2 \times .000170 IS^2}; \tag{4}$$

$$= 162{,}000{,}000 \frac{T}{IS^2}(p - p_1). \tag{5}$$

Now the relation between speed of revolution and kinetic energy of the revolving parts is evidently

$$\frac{K_1}{K} = \frac{S_1^2}{S^2}. \tag{6}$$

By algebra,

$$\frac{K_1 - K}{K} = \frac{S_1^2 - S^2}{S^2}; \tag{7}$$

$$= \frac{(S_1 + S)(S_1 - S)}{S^2}. \tag{8}$$

Putting $S_1 - S = \Delta S$

and $K_1 - K = \Delta K$.

For small differences between S and S_1, this becomes approximately

$$\frac{\Delta K}{K} = \frac{2S\Delta S}{S^2}. \tag{9}$$

$$\therefore \frac{\Delta K}{K} = \frac{2\Delta S}{S}. \tag{10}$$

Substituting (10) in (5), $$\frac{200\Delta S}{S} = 162{,}000{,}000 \frac{T}{IS^2}(p - p_1). \tag{11}$$

$$\therefore \delta = \frac{100\Delta S}{S} = 81{,}000{,}000 \frac{T}{IS^2}(p - p_1). \tag{12}$$

If $p = HP$, $p_1 = 0$, and $T = 1$,

then the percentage speed variation for 100 per cent. load change, if the governor makes a complete stroke in one second, is

$$\frac{100\Delta S}{S} = \frac{81{,}000{,}000\,HP}{IS^2}. \tag{13}$$

From the form of equation (12) it is apparent that the percentage speed variation is directly proportional to the slowness of the governor; *e. g.*, if T is four seconds, the variation in speed is four times as great as when T is one second. Under certain conditions the effect of the governor in promptly adjusting the output of the water wheel after a load change is interfered with by the inertia of the water column in the pentstock, and in such cases the predetermination of speed variation is sometimes very difficult. For simple deflecting nozzles with tangential wheels and with most turbine installations the formula (12) is of great service.

Of the quantities in the equation (12), there is one, viz., T, which cannot be exactly determined. Any governor manufacturer will state the time required for a complete stroke of one of his governors, but it should not be assumed that fractions of the stroke will be covered in correspondingly lesser intervals. Experience shows that short governor movements take place at a much slower rate of travel than long ones. It is necessary that this should be so in order to prevent overtravel in adjusting the output of the water wheel. As a matter of fact, one may assume, without introducing a serious error into the calculations, that the time T required for any governor to alter the power of a water wheel after a great or small sudden load change will be approximately constant and equal to the time required for a full stroke.

As an application of the foregoing formula consider the following simple problem:

Given an 8,000 horse power tangential wheel with deflecting nozzle, running at 400 revolutions per minute, driving a revolving field alternator. The fly wheel effect or $\int wr^2$ of the revolving parts is estimated equal to 500,000 pounds at 1 foot radius. The speed of action of the governor will be one second for a full stroke. Required the percentage speed variation for (*a*) 100 per cent., (*b*) 50 per cent., and (*c*) 10 per cent. load changes.

Referring to equation (12),

$$T = 1, \quad I = 500{,}000, \quad S = 400.$$

(*a*) For 100% load change $(p - p_1) = 8{,}000$.

(*b*) For 50% load change $(p - p_1) = 4{,}000$.

(*c*) For 10% load change $(p - p_1) = 800$.

Substituting in equation (12),

$$(a) \quad \delta = 81{,}000{,}000 \frac{1 \times 8{,}000}{500{,}000 \times 400^2} = 8.10\%.$$

$$(b) \quad \delta = 81{,}000{,}000 \frac{1 \times 4{,}000}{500{,}000 \times 400^2} = 4.05\%.$$

$$(c) \quad \delta = 81{,}000{,}000 \frac{1 \times 800}{500{,}000 \times 400^2} = .81\%.$$

After a power plant is in operation, it is often necessary to determine, among other facts, whether the speed regulation is as good as was guaranteed by the governor manufacturer, or at any rate as good as it should be. The instruments for making such tests are as numerous as they are unreliable. Ordinary tachometers cannot be depended upon at all unless they have been carefully calibrated, and even then most of them have defects which make accurate determinations impossible.

There is another class of instruments, known as frequency indicators, upon which reliance is sometimes placed. These have nicely graduated scales, with proportional divisions purporting to show changes in frequency, cycle by cycle. If they told the truth they would be exceedingly useful, for by merely connecting one of them in circuit with an alternator it would be possible to tell immediately the speed variations occurring either in connection with the regular operation of a plant or during prearranged variations in load. These frequency indicators are generally correct for the number of cycles where they are intended to be used, but cannot usually be depended upon over any range of scale.

A method of obtaining simultaneous measurements of load, voltage, and speed has been devised by the author which is absolutely free from instrumental defects, and which, while requiring only one or two skilled men for its use, will give results of great value in any power plant where there are two or more independent alternating current units.

It is evident that the number of cycles per second of current generated by any alternator could be used to measure the speed if these cycles could be accurately counted. The oscillograph provides means for doing this in a very interesting way. This instrument, which is well known to electrical engineers, is a sensitive reflecting galvanometer, which has such an exceedingly short period of vibration and is so deadbeat in action that the actual current wave, varying, even though it may, as rapidly as several hundred times a second from a

positive to a negative value, can be accurately followed and recorded on a sensitive photographic film. If the film could be moved at an absolutely uniform rate, so that the trace of the current value would be drawn as an approximate sine curve, it would be necessary merely to measure the spacing of this curve in order to determine the frequency of the generator and, consequently, its speed. It is not easy, however, to provide absolutely uniform motion for the film, and there are some other difficulties in the way. Since, however, several oscillograph curves may be superimposed on the same film, it is not necessary that the sensitive photographic surface should move at a uniform rate, because one sine curve may be measured in the terms of another sine curve. If one of these is known to pass through a constant number of cycles per second, it may be adopted as the standard unit of time, and its waves, as shown on the film, be used to measure the number of cycles per second of the other curve and, consequently, the speed variations of the machine under test.

The measurement of the comparative frequency of the two curves becomes a very simple matter if they are allowed to overlap on the film, because in such a case interference effects are produced in a very beautiful manner. These interferences are due to the fact that at times the traces of both curves overlap on the film so as to produce a single line; while at other times, one curve having gained part of a cycle over the other, the two lines will be side by side and more or less confused. When the speed of motion of the film is right, the negative shows alternate shaded bands, the distance apart of which, when counted in cycles, is an accurate measure of the relative speeds of two generators being compared; and if one of these generators is running at constant speed, it gives an absolutely clear record of the very smallest variations in speed of the other machine. It will be observed that there are no possible instrumental errors by this method. Inertia, sluggishness, friction, faulty calibration, and other objectionable features of mechanical devices are wholly eliminated, and results are obtained which must be considered absolutely final if just one condition is fulfilled. Everything depends upon one generator running at constant speed. In practice it is not difficult to fulfill this condition with ample precision. To do so the generator, which is to serve as a standard measure of time, must be given a perfectly steady load, or, better still, no load at all, excepting the trivial current required by the oscillograph. The gate of the water wheel which drives it should

be disconnected from its governor and fixed in position. The water pressure upon the wheel should be maintained very nearly constant. The generator should be allowed to run fifteen or twenty minutes before measurements are made. Its speed should be observed very carefully by a sensitive recorder of some kind in order to be sure that it is steady. A frequency indicator will answer very well for the purpose, even though its graduations may be far from correct, because it is to be borne in mind that steady speed is the only desideratum. The great inertia of the revolving parts of the water wheel and generator in the absence of any external load will be found to maintain the speed with remarkable uniformity. There should be no trouble at all in keeping this standard machine steady within 0.1 per cent. without any difficult manipulation of the water wheel gate. The frequency of this standard machine should be adjusted 5 per cent. or 6 per cent. below or above that of the normal frequency of the machine of which the speed is to be measured.

Assuming that the standard generator is running 5 per cent. in speed below the normal frequency of the machine under test, which is the case with the curves shown (Fig. 8), it is clear that the fast machine should gain five cycles over the standard in 100 cycles; or, in other words, the interference points should be twenty cycles apart. If, however, the machine under test should drop in speed 5 per cent., it would then have the same frequency as the standard machine, and the interference points would be an infinite distance apart. If the loaded machine should gain 5 per cent. above its normal speed, it would then be 10 per cent. faster than the standard one, thus gaining ten cycles in each 100, so that the interference bands would be spaced at ten cycle intervals. The extreme precision of the method is shown in the large variation in the spacing of these interference bands, corresponding to comparatively small variations in relative speed. Another great advantage of the method over any other, however, lies in the fact that not only is the speed of a machine under operating conditions determined with extreme precision, but also that the voltage of such a machine is recorded simultaneously, for the amplitude of the oscillograph curve depends precisely upon the voltage of the machine being tested. By measuring the width of the curve, the voltage value corresponding to each speed value is obtained.

Furthermore, it is possible to obtain simultaneous measurements of the current output from the loaded machine; which means practically

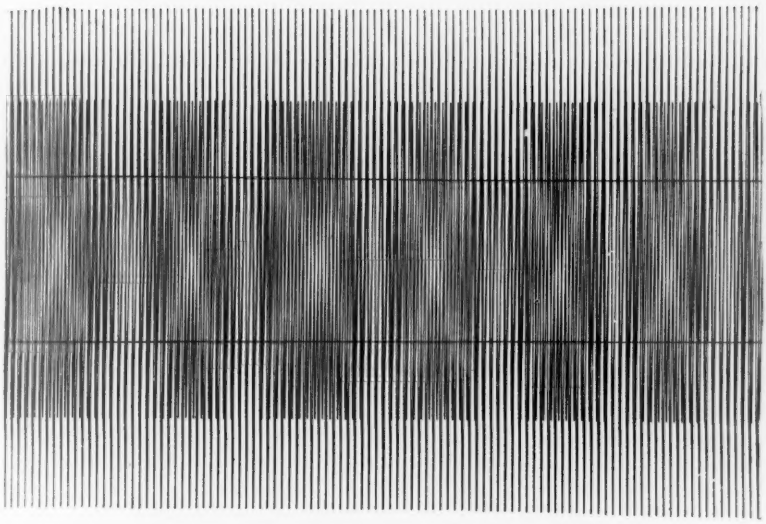


FIG. 8. — OSCILLOGRAPH RECORD FOR SIX SECONDS
Middle horizontal lines indicate amplitude of current curve

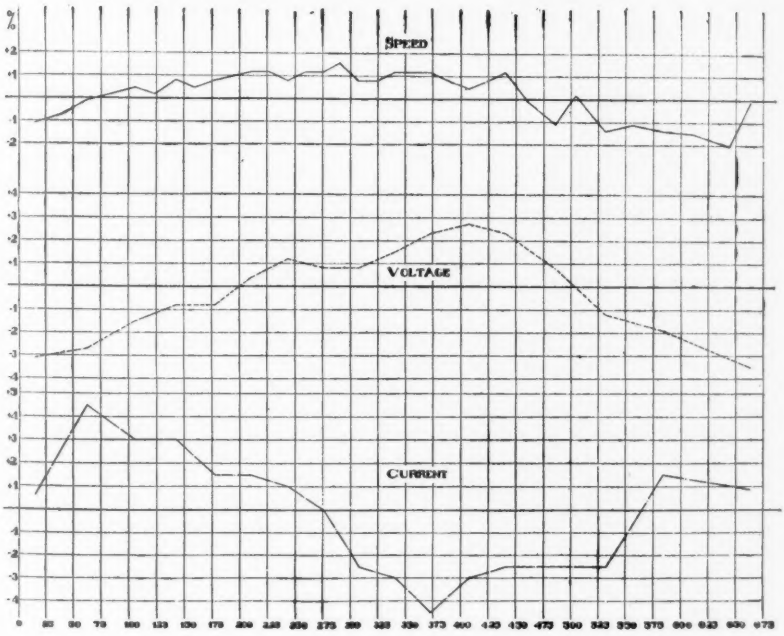


FIG. 9. — PLOT SHOWING RELATION OF SPEED, VOLTAGE, AND CURRENT FROM OSCILLOGRAPH RECORD ABOVE

the variations in load, and this is the most important feature of all. To do this a third oscillograph mirror is impressed into service, being connected with a current transformer in circuit with the generator under test, so that the amplitude of the curve traced by the light reflected from this mirror shall indicate at every point on the sensitive film what the actual output of the generator was, corresponding to the speed and voltage shown by the other two curves. Such a record sheet as has been described, one-fourth of which is shown in the chart (Fig. 8), reproduced with the omission of the current curve of which the amplitude is indicated, contains a marvelous amount of information to the one who can read its secrets. The speed, voltage, and current curves which are shown were obtained by a careful analysis of the entire original record, which is 4 inches wide and about 12 inches long. The lines are spaced so closely on this record as to require the use of a weak microscope in order to make them clear, but there is no possible question about the accuracy of all the results which are given. This method makes it possible to conduct a speed test of any alternating current unit, either steam or water driven, under actual load conditions, and is therefore of much greater value than any test, however accurate, under special conditions, which are never exactly the same as when in service.

MAXIMUM LIVE-LOAD BENDING MOMENTS AND SHEARS FOR BRIDGES CARRYING ELECTRIC CARS[1]

By FRANK P. McKIBBEN

In designing bridges to carry electric railways one should bear in mind that besides the ordinary passenger cars there are other types which frequently should be considered, namely, construction, service, and freight cars. The development of freight traffic upon electric roads makes the consideration of the freight car an important element in choosing loads to be used in designing. However, as the weight and wheel spacing of service and construction cars will vary widely from case to case, only passenger cars will here be considered.

In the last eight or ten years the increase in weight of single-truck cars has been so small and that of double-truck cars so large that, in designing, the latter type only need be used. Except in some special cases of unusually heavy urban or interurban railways, it seems reasonable to assume for a passenger car a double-truck car weighing, together with its maximum load, 100,000 pounds. This should be sufficient to provide for a considerable future increase in weight of cars; but, judging from past experiences with such increases of locomotives on steam railroads, it is difficult to predict with any certainty regarding future loadings for electric cars. In the special cases to which reference is made above, where unusually heavy cars are now in use a loading of 120,000 pounds should be used. It should be remembered that the weight of a car is sometimes unequally distributed over its wheels.

The average unloaded weight of the heaviest double-truck passenger cars now being operated upon fifty-seven electric railways of Massachusetts is 40,000 pounds. The smallest weight used in finding this average is 20,000 pounds and the largest 72,800 pounds. These figures give the weight of the car alone. Assuming 150 passengers at 120 pounds each, the loaded weight of the average car becomes 58,000 pounds and the maximum 90,800 pounds. The average wheel base of a truck for these cars is 5 feet, and the average distance centre to

[1] Reprinted, with slight alterations, from Engineering News, April 4, 1907, 57, No. 14, 372–373.

centre of trucks is 20 feet. This makes the spacing between rear wheel of front truck and front wheel of rear truck 15 feet. The wheel spacing between cars, when two or more cars are run coupled, will not be far from the same amount, so that the concentration of a single car is to be regarded as a maximum for all spans less than 45 feet long.

The criterion for finding the position of a system of concentrated wheel loads to produce the greatest possible bending moment upon a given span is found as follows:

Let the span and loads be as shown in the figure on page 214.

R is the resultant of all the loads on the span, x its distance from the right support, and a its distance from the load P_3. Neglecting the dead load and considering only the concentrated loads, it is evident that the maximum moment will occur at a wheel which is near the centre of the span. The expression for the moment at P_3, this load being one near the centre of the span and nearest the resultant of the loads on the span, is,

$$M = \frac{Rx}{L}(L - x - a) - \Sigma Pd, \tag{1}$$

where ΣPd is the summation of the moments about P_3 of the loads to the left of P_3.

To find the position of the resultant R such that the moment at P_3 is the greatest that can occur at P_3, with the assumed loads on the span, we must differentiate equation (1), place the first differential equal to zero, and solve for x, thus:

$$\frac{dM}{dx} = \frac{R}{L}(L - 2x - a) = 0. \tag{2}$$

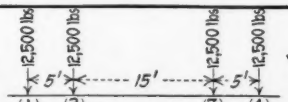
Solving equation (2) for x, we have,

$$x = \frac{L}{2} - \frac{a}{2}.$$

This value of x shows that if the loads assumed are on the span the maximum moment possible at load P_3 will occur when the *centre of the span is midway between the load P_3 and the resultant R.*

In applying this principle, it will generally happen that not all the wheels of a series can be placed on the span at one time, at least not in such position as to satisfy the condition as to the resultant R. It then becomes necessary to try several positions of the series of loads. The method of procedure is, then: Assume some of the loads on the

TABLE OF LIVE-LOAD END SHEARS AND MOMENTS IN BRIDGES CARRYING ELECTRIC CARS



Maximum End Shears						Maximum Moments					
Span in Feet	Wheels on Span for Max.	Max. End Shear (lbs. per Rail)	Span in Feet	Wheels on Span for Max.	Max. End Shear (lbs. per Rail)	Span in Feet	Wheels on Span for Max.	Max. Moment (ft. lbs. per Rail)	Span in Feet	Wheels on Span for Max.	Max. Moment (ft. lbs. per Rail)
5		12500	51		37700	5		15600	51		401300
6		14600	52		38000	6		18800	52		419500
7		16100	53		38200	7		21900	53		425800
8		17200	54		38400	8		25000	54		438000
9		18100	55		38600	9		29300	55		460300
10		18750	56		38800	10		35200	56		462600
11		19300	57		39000	11		41100	57		474800
12		19800	58		39200	12		47000	58		487100
13		20200	59		39400	13		53000	59		499400
14		20500	60		39600	14		59000	60		511700
15		20800	61		39800	16		65100	61		524000
16		21100	62		39900	16		71200	62		536300
17		21300	63		40100	17		77300	63		548700
18		21500	64		40200	18		83400	64		561000
19		21700	65		40400	19		89600	65		573300
20		21900	66		40500	20		95700	66		585700
21		22600	67		40700	21		101900	67		598000
22		23300	68		40800	22		108000	68		610300
23		23900	69		40900	23		114200	69		622700
24		24500	70		41100	24		120400	70		635000
25		25000	71		41200	25		126600	71		647400
26		26000	72		41300	26		132800	72		659800
27		26900	73		41400	27		138900	73		672100
28		27700	74		41600	28		145100	74		684500
29		28400	75		41700	29		151300	75		696900
30		29200	76		41800	30		159700	76		709300
31		29800	77		41900	31		169000	77		721600
32		30500	78		42000	32		178300	78		734000
33		31100	79		42100	33		187500	79		746400
34		31600	80		42200	34		196800	80		758800
35		32100	81		42300	35		207600	81		771200
36		32600	82		42400	36		219500	82		783600
37		33100	83		42500	37		231500	83		796000
38		33600	84		42600	38		243500	84		808400
39		34000	85		42600	39		255500	85		820800
40		34400	86		42700	40		267600	86		833200
41		34800	87		42800	41		279600			
42		35100	88		42900	42		291700			
43		35500	89		43000	43		303900			
44		35800	90		43100	44		316000			
45		36100	91		43100	45		328100			
46		36400	92		43200	46		340300			
47		36700	93		43300	47		352500			
48		37000	94		43400	48		364600			
49		37200	95		43400	49		376900			
50		37500	96		43500	50		389100			

span so as to bring the heavy loads as near the centre of the span as possible and so as to have as many loads on as possible. Find the position of the resultant of these loads, and place the centre of the span midway between the resultant and the nearest load. If all the loads

assumed on are now really on the span, compute the moment at the nearest load just mentioned. If when the above assumed loads are placed in the position just cited some of the loads assumed on the span are really off the span, it is then necessary to try again, using a new resultant. Unless one can tell by inspection, it would be necessary to compute in this manner the maximum moment at several of the loads until the greatest possible moment is found. This latter is called the absolute maximum moment. It is evident that when the resultant coincides with one of the loads the greatest possible moment that can occur at this wheel is when it and the resultant lie at the centre of the span.

Passing now to the study of the absolute maximum moments under a double-truck electric car with four equal axle loads with a wheel spacing of 5—15—5 feet, as shown at the head of the subjoined table, we see that there are four cases, namely, where the maximum moment is caused respectively by one, two, three, or four loads on the span. Obviously for certain short spans only one load on the span will cause the maximum; for somewhat longer spans two loads, etc. The limiting lengths separating these groups can be computed.

Case 1. One Load Only on the Span.—The maximum moment will occur at the centre when the load is at the centre. It is equal to

$$M_1 = \frac{PL_1}{4}, \tag{3}$$

where P is one wheel load and L_1 is the length of span.

Case 2. Two Loads on the Span.—Place the wheels so that the centre of the span comes midway between the resultant of the two loads and one of the loads, and the maximum moment will occur at the load which is 1¼ feet from the centre, and is equal to

$$M_2 = \frac{2P\left(\frac{L_2}{2} - \frac{5}{4}\right)^2}{L_2}. \tag{4}$$

Case 3. Three Loads on the Span.—The resultant of three loads will lie 3⅓ feet from load No. 2. Hence the maximum moment will occur at wheel No. 2 when the centre of the span lies 1⅔ feet from the load and is equal to

$$M_3 = \frac{3P\left(\frac{L_3}{2} - \frac{5}{3}\right)^2}{L_3} - 5P. \tag{5}$$

Case 4. Four Loads on the Span. — The maximum moment will occur at load 2 when this load is 3¾ feet from the centre, and is equal to

$$M_4 = \frac{4P\left(\frac{L_4}{2} - \frac{15}{4}\right)^2}{L_4} - 5P. \qquad (6)$$

By equating equations (3) and (4) and calling $L_2 = L_1 = L$, we can find the length of span below which only one load will produce the maximum moment and above which two loads 5 feet apart will give greater moments than the single load, thus:

$$\frac{PL}{4} = \frac{2P\left(\frac{L}{2} - \frac{5}{4}\right)^2}{L},$$

from which $L = 8.5$ feet.

Similarly, by equating equations (4) and (5) we find the length of span below which two wheels give greater moments than three wheels,

$$\frac{2P\left(\frac{L'}{2} - \frac{5}{4}\right)^2}{L'} = \frac{3P\left(\frac{L'}{2} - \frac{5}{3}\right)^2}{L'} - 5P,$$

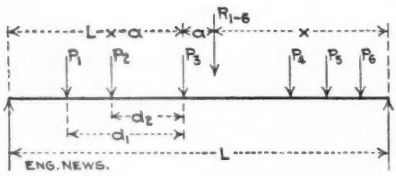
from which $L' = 29.3$ feet.

In a similar manner, by equating equations (5) and (6), we find that L'' equals 34.4 feet; that is, for spans less than 34.4 feet three wheels give greater moment than four wheels, while for spans over 34.4 feet four wheels give the greater moment.

It is customary to add to the above absolute maximum live-load moment the dead-load moment at the centre of the span. Except in cases where the absolute maximum moment occurs at the centre of the span, this is slightly incorrect, but is on the safe side.

The determination of the maximum end shears is very simple. It is evident that for spans of 5 feet and under the maximum end shear will occur with one wheel on the span; for spans between 5 and 20 feet with two wheels; between 20 and 25 feet three wheels; and above 25 feet four wheels on the span. In each case the leading wheel is placed just at the support.

The accompanying table of moments and shears has been worked out for a 100,000-pound car with a wheel spacing of 5—15—5 feet, and has been carried to those lengths of spans where a uniformly



distributed load of 1,800 pounds per foot of track causes maximum moments and end shears equal to those caused by one car.

It is interesting to notice that if the dead load be taken into account the common derivation for the maximum moment at load P_3 is incomplete. The expression for the moment may be written as follows, with reference to the accompanying figure:

$$M = \frac{Rx}{L}(L - x - a) - \Sigma Pd + w(L - x - a)\frac{(x + a)}{2},$$

where w is the uniform load per unit of length. The value of x, which will make M a maximum, is obtained by differentiating this equation with respect to x, and placing the result equal to zero. This process gives

$$x = \frac{L}{2} - a\left(\frac{wL + R}{wL + 2R}\right).$$

Since in this value of x the part within the parentheses is greater than one-half, the value of x is less than for the case where only the live load was considered; which means that for the exact absolute maximum moment the load P_3 should be slightly nearer the centre than previously found.

To compare the usual with this exact method let us take a 60-foot span with a 100,000-pound car and a total dead weight of 800 pounds per foot. The absolute maximum moment for the live load alone is

$$= \frac{50000(30 - 15/4)^2}{60} - 62{,}500 = 511{,}719 \text{ foot pounds per rail.}$$

The dead-load moment at the centre is 180,000 foot pounds per rail. The customary approximate method of adding the absolute maximum live to the maximum dead moment would, therefore, give in this case a total amount of 691,719 foot pounds; whereas the correct method would give a combined maximum moment of 689,451 foot pounds. All of which goes to show that the customary approximate method is sufficiently accurate.

The analysis and computations in this article deal only with bridges in which the load comes directly on the main girders.

TRIP OF THE AMERICAN INSTITUTE OF MINING ENGINEERS TO MEXICO[1]

By ROBERT H. RICHARDS

THE American Institute of Mining Engineers held their fall meeting in Mexico, in November, 1901. The members were carried on two trains, which most of the engineers joined in Chicago, and visited various points in Mexico, holding their official meetings for the reading of papers in the different towns as they went, visiting the mines, concentration works, amalgamation works, and smelters.

The Institute was received in the most cordial manner by the Mexicans, who treated them really as the nation's guests. Nothing that could be done for the comfort of the engineers was omitted. On the arrival of the trains in a town the bands played, the members were decorated with flowers as they came from the train, and were officially welcomed by the officials of the town; means were provided to send them to the mines or works in the neighborhood, and in many cases balls and banquets were given in honor of the guests. Such profusion of kindness and generosity was difficult to reciprocate, but the mining engineers did so to the utmost of their ability.

Among the many pleasant things that were done, loving cups were given to Carlos F. Landero and Rafael de Arozarena, both of whom were leaders in the entertainments.

The Mexican bull fight is the greatest treat, in the eyes of the Mexicans, that can be offered to guests. Accordingly, one was provided at Chihuahua, the first place visited. The engineers and their wives all went to see the bull fight, in order to show their appreciation of the delicate attention shown by the Mexicans. It was, however, quietly whispered over the wires that the bull fight was not the American idea of entertainment, and, as a result, no further invitations were given.

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[1] A talk before the Mining Society of the Massachusetts Institute of Technology on Tuesday, 9 April, 1907.

A visit was made from Chihuahua to the Descubridora mine, from which a great deal of rich silver ore has been shipped to the smelters. The ancient pateo process for amalgamation of silver ores was inspected at several places, Zacatecas and, best of all, Pachuca.

The pateo process of Mexico and South America is one of great interest, both from its early appearance as a means of extracting silver and on account of its comparatively high efficiency. The process consists in breaking by hand to about 1 inch in size, by an edge roller to the size of Indian corn, and by an arastra, or drag stone, down to pass through about a 60-mesh sieve. The amalgamation takes place in an open yard called pateo, with very smooth pavement of stones, made so as to be impervious to mercury and water.

The finely pulverized ore, in the condition of mud, is run out on to this pavement and penned into areas holding about 500 tons each. It is then allowed to dry sufficiently for the subsequent operation. The pulp is stirred by turning mules and horses in to walk about in it, the layer of mud being about a foot thick. These animals stir the mud for twelve hours in the day. At periodic intervals mercury is sprinkled in, and the consistency of the mud is held so as to prevent the mercury from settling quickly through it to the bottom. The stirring by the animals brings the mercury in contact with the ore particles and the ore in contact with the air. After several weeks of stirring, adding mercury, testing to ascertain the condition of the extraction, and the adding of chemicals, the whole mass of pulp is liquefied by water and run out into a separator, where the amalgam is caught and the tailings run to waste. The amalgam is then distilled, the mercury recovered, and the residue is melted into bars and shipped to the mine.

At Guanajuato is the ancient silver vein, from which it is said two thousand million dollars of silver have been taken in two hundred years; at Guadalahara, the home of the Mexican drawn work, the wives of the engineers had a special treat; in Mexico City the engineers were cordially welcomed by President Porfirio Diaz in his castle at Chapultepec, from which a glorious view could be had of the beautiful snow mountains Popocatepetl and Iztaccihuatl. The wonderful old aqueduct standing on arches is well represented by fragments; the monster drainage canal which has saved the city from destruction by turning away the water from the old lake bottom in which the city is situated proved especially interesting.

The cathedral in Mexico City, which is the finest in Mexico and

one of the fine cathedrals of the world, was visited by the party. An extremely interesting visit was made to the wonderfully rich cathedral at Guadalupe. The priesthood of this cathedral owned a silver mine, and much of the silver was used in enriching the various altars, altar rails, and other parts of the building. At Cuernavaca the engineers saw the beautiful home of Cortez, and later of Maximilian, where these potentates delighted to live during their vacations from the active work of governing the nation.

At Aguascalientes the engineers took a bath in one of the hot springs, and at this point, as well as at San Luis Potosi and Monterey, they visited the great silver lead smelting establishments. At the latter place they also found the extensive new iron works for smelting iron and making Bessemer steel. At Tampico they took a dip in the Gulf of Mexico, with flocks of funny pelicans flying about, but they were warned to keep in shallow water for fear of sharks.

Coming north they visited the gold mine of Baratoran, and then came up by way of Eagle Pass into the States. They passed through the great Houston oil region of Texas just at the time it was reaching its climax.

When the engineers sought for a means of expressing their gratitude to the Mexicans which would be most highly appreciated, they found it to be in the placing of a profusion of beautiful flowers, in which Mexico abounds, upon the grave of Juarez, the patriot president.

The paper was illustrated by lantern slides showing the points mentioned above and many others.

THE HEALTH OF EMPLOYEES IN THE NEW YORK SUBWAY

By GEORGE A. SOPER

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INTRODUCTION

This paper is practically identical with a report made in May, 1907, to the Board of Rapid Transit Commissioners for the city of New York, and describes an investigation into the possible effects of the metallic dust of the subway on the health of the employees.

This work was the outcome of an investigation made in 1905 concerning the condition of the subway air, which was described in a paper read by the author before the Society of Arts, November 22, 1906.[1]

Acknowledgment of Assistance

Thanks are due to many persons for help. The Interborough Rapid Transit Company, through Mr. Frank Hedley, General Manager, granted requests for information concerning the men and furnished the 100 employees who were examined.

The physical examinations and analyses were made with much skill

[1] The Technology Quarterly, **20**, No. 1, March, 1907.

by Dr. James Alexander Miller, Instructor in Physical Diagnosis at the College of Physicians and Surgeons, assisted by Doctors H. C. Hanscom, J. M. O'Connor, and I. O. Woodruff. In the autopsies and subsequent histological examinations thanks are due to Dr. J. H. Larkin, Adjunct Professor of Pathological Anatomy, and to coroner's physicians, Doctors T. D. Lehane and P. F. O'Hanlon. To Dr. Frank B. Mallory, Associate Professor of Pathology, Harvard Medical School, who collected records to show the pleurisy found in 1,008 autopsies performed at the Boston City Hospital, the author is also indebted. Finally, a number of eminent pathologists and medical practitioners aided the work by valuable suggestions and opinions.

PLAN OF THE INVESTIGATION

It was intended that the investigation should be so made as to detect any physiological effects which might be caused by the dust of the subway, whatever they might be. Special care, however, was taken to look for early signs of more serious disease of the lungs, which exists to an excessive extent among persons engaged in dusty occupations.

Physical examinations were made of a sufficient number of subway employees to determine the condition of the average man. Supplementary to these, bacteriological and chemical analyses were made of their sputum, urine, and sweat.

To determine to what extent dry pleurisy existed among persons not engaged in subway work, examinations were made of 200 men, representing twenty different occupations.

To help arrive at an understanding of the possible effects of the subway dust, data were collated concerning its chemical composition, physical properties, and the weight of dust in a given volume of subway air. The bacteria associated with this dust were also considered.

The condition of the air and the work of the men were compared with the conditions which exist in such vocations as stonecutter, knife grinder, metal polisher, and other dusty occupations in which a high mortality occurs.

It being desirable to obtain an accurate understanding of the anatomical condition of the men, and as this could be had only by dissecting their bodies after death, arrangements were made to have as many autopsies as practicable performed upon the remains of

employees killed by accident in the subway during the period covered by the investigation.

Light was thrown upon the frequency with which pleurisy was found at autopsy by reviewing the records of a large number of reports of *post-mortem* examinations made elsewhere.

THE CONDITION OF THE AIR

Investigations which were made for the board from July, 1905, to January, 1906, showed that the chemical condition of the air of the subway, in spite of unpleasant odors and heat, was remarkably good.

Carbon dioxide, the measure of vitiation used as determined by 2,084 analyses covering practically all times and places, was found to be but little higher in the subway than in the streets. The average for the subway was 4.81, and for the streets 3.67. These figures represent parts of carbon dioxide in 10,000 volumes of air.

There was ample oxygen. The average of eighty analyses gave 20.60 per cent. of oxygen for the subway as against 20.71 per cent. for the streets.

The analyses, checked by observations of air currents, indicated that the atmosphere of the subway was completely renewed at least every half hour before any material improvements were made in the methods of ventilation.

There were two principal reports made to the board as a result of the air investigations.[1] A paper dealing with the facts more especially of medical interest was read before the New York Academy of Medicine on March 15, 1906.[2] A second paper dealing with the analytical and meteorological methods was read before the Society of Arts at Boston on November 22, 1906, and published in the TECHNOLOGY QUARTERLY,[3] Boston.

Summarizing the opinions which the author formed at the conclusion of that investigation, the principal possibilities for harm in the air, aside from rapid changes of temperature and strong draughts, lay in the presence of the black metallic dust. The principal characteristics of this dust will now be described.

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[1] New York City Record, February 27, 1906.

[2] New York Medical Record, April 21, 1906.

[3] Vol. 20, No. 1, pp. 58–118.

Physical and Chemical Composition of the Dust

When examined microscopically the dust was found to be composed of particles of many substances, including innumerable fine, flat plates of iron. These iron particles could be seen by a sharp eye glistening upon the hats and garments of persons after a short ride in the subway. The clothing of the employees gathered this dust, and their hands, bodies, and linen became discolored with it.

Large particles of iron could readily be seen at the stations glistening upon the roadbed. A common horseshoe magnet suspended at the breathing line would in a few days collect a surprisingly large amount of iron dust. On one occasion a magnet carried by a passenger on a ride of twenty minutes gathered a particle from the air which measured 2 mm. in length. Of three magnets hung up — one at the Grand Central Station of the subway, another in a dry grinding establishment, the third in an iron foundry — the subway magnet collected by far the most dust.

Eleven samples of subway dust were analyzed chemically, with results given in the following table:

TABLE I

Results of Chemical Analyses of Eleven Samples of Subway Dust

Date, 1905.	Place of collection.	Total iron.	Silica, etc., insoluble in acids.	Oil.	Volatile and organic matter.
		Per cent.	Per cent.	Per cent.	Per cent.
August 3	96th Street station	63.07	12.79	0.88	23.26
August 3	14th Street station	41.77	26.39	1.43	30.41
August 14	Grand Central station	67.35	12.65	1.23	18.77
August 18	23d Street station	54.36	20.50	0.99	24.15
August 17	Brooklyn Bridge station	45.72	21.79	1.97	30.52
August 21	33d Street station	69.66	12.34	0.91	17.09
August 21	Canal Street station	74.78	9.46	0.80	14.96
September 19	116th Street and Lenox Avenue station	66.69	13.84	0.96	18.51
September 19	Times Square station	68.42	7.45	1.00	23.13
September 20	18th Street station	59.84	17.94	1.43	20.79
September 20	28th Street station	62.58	16.28	1.42	19.72
	Average	61.30	15.58	1.18	21.94

A glance at this table shows that the average amount of iron in the dust was 61.3 per cent. The samples were collected from smooth,

clean surfaces upon which the dust had been allowed to settle from the air.

In addition to the iron particles, the dust contained bits of silica, cement, stone, fibers of wood, wool, cotton, silk and other textile materials, molds, and indistinguishable fragments of refuse of many kinds, resulting from the wear and tear of the subway and the clothing of the passengers. In fact, everything in the subway susceptible of wear contributed to the dust. In addition, refuse from the streets was carried into the subway by inflowing currents of air and by passengers.

Bacterial Composition of the Dust

On the whole the numbers of bacteria found in the dust of the subway were smaller than the numbers found in dust from the streets. The average obtained on analyzing thirty samples of dust from the subway was 500,000 per gram of dust. The average number found on analyzing 141 samples of subway air was 3,200 per cubic meter. These figures were about one-half as large as were found for the streets.

These numbers represent bacteria capable of growing on beef extract agar, of ½ to 1 per cent. acid reaction to phenolphthalein, at the temperature of the body and at such a rate that colonies could be counted at the end of forty-eight hours.

There was reason for believing that some of the bacteria in the subway were more harmful than those generally found outside. The absence of sunlight in the subway prolonged the life of the germs of some diseases. The pneumococcus, believed to be the cause of lobar pneumonia, was found by experiment to be capable of living twenty-one days in the subway as against four days in the streets.

The lack of enforcement of the ordinance against spitting and the frequency with which passengers and employees expectorated upon the tracks, platforms, and stairways increased the danger from tuberculosis and other respiratory diseases. The excessive crowding exposed the employees, particularly those holding the grades of guard and conductor, to a still greater danger of infection.

Sources of the Iron Dust

A large part of the metallic dust came from the wear of the brake shoes upon the steel rims of the wheels under the cars. It was calcu-

lated that one ton of brake shoes was ground up on every mile of the subway every month. In addition, there was some loss of metal from the rails, especially at the curves. So great was this wear that an especially durable steel was at length made to withstand it.

The rims of the wheels and the contact shoes which supplied the motors under the cars with electricity from the third rail contributed some weight of metal to the dust. Probably twenty-five tons would be a low estimate of the total weight of iron and steel ground up in the twenty-one miles of subway every month.

It must not be supposed that all of this great amount of ground iron floated in the air. Some of the pieces were so large that they fell immediately to the track and remained there. Others were raised only for brief moments by violent eddies produced by the trains. Large quantities were caught by the ties and broken stone ballast, which were continuously sprinkled with lubricating oil from the trains. Many of the particles were so greasy that they adhered firmly to whatever surfaces with which they happened to come in contact. The smallest and probably the freshest particles remained longest in the air. It was these which constituted the dust used in the analyses. It was these which were breathed.

Some dust was carried up into the streets by air currents which were forced out through the station stairways and blowholes by the trains. The trains also kept the dust in suspension in the subway. Had there been no trains the dust would have quickly settled from the air. This is shown by the bacteriological experiment recorded in Table II, in which the bacteria acted like exceedingly minute dust particles.

TABLE II

EFFECT ON THE NUMBERS OF BACTERIA IN THE AIR OF THE SUBWAY PRODUCED BY A SUSPENSION OF THE TRAFFIC WHICH LASTED ONE HOUR, NOVEMBER 11, 1905

Place of collection.	Time.	Microörganisms per Cubic Meter of Air	
		Bacteria.	Molds.
110th Street and Broadway station, north end, east platform. Soon after the collection of the first sample all trains stopped running	10.20[a]	1,300	0
	10.37[a]	750	0
	10.55[a]	400	0
	11.15[a]	250	0
Average	..	700	0

Weight of Dust in Air

The average weight of dust in subway air was found to be 61.6 mg. per thousand cubic feet of air, or 2.25 mg. per cubic meter. This was somewhat more than was found in the streets under parallel conditions. The figures for the streets were 52.1 mg. per thousand cubic feet, or 1.83 mg. per cubic meter. The average for the subway is made up of the results of 146 analyses made at points and at times especially selected to give a correct knowledge of the normal conditions.

These analyses show that the total amount of dust in all of the air contained in the subway at any time from the 96th Street station to the Brooklyn Bridge was 3½ pounds. The dust was not quite evenly distributed through the air. There was more dust at express stations than elsewhere. At any given station there was more dust at the arrival ends of the platforms than at the departure ends. The difference was, however, very slight.

Weight of Dust Inhaled

The weight of dust which an employee took into his mouth or nose during the course of a day of ten hours could be computed from the results of the analyses just referred to. Assuming that 360 c.c., or 22 cubic inches, of air were taken in at each breath, and the employee breathed at the average rate of eighteen times per minute, the total quantity of air which passed into his lungs in ten hours was 6.86 cubic feet, or .19425 meter. Taking 61.6 mg. per thousand cubic feet as the weight of dust suspended in the atmosphere, it is found by calculation that an employee took into his nose or mouth 8.4 mg. of dust in ten hours. This is 3,066 mg. per year, or forty-six grains. It will be shown presently that only a small part of this could get into the lungs.

Reliable data are lacking to show the weight of dust which exists in the air of steel-grinding and other establishments where disease is produced by dust. Hesse found, some years ago, from 72 to 100 mg. of dust in a cubic meter of air in an iron foundry, and 14 mg. per cubic meter in the air of an iron mine.

THE DANGERS OF THE DUST

The possibility of the dust causing injuries to the eyes, to the skin, and to the respiratory apparatus was considered in this investigation;

but the condition of the throats and lungs of the employees received the largest share of attention.

Injurious Properties of Subway Dust

Inasmuch as dust may do harm in many ways, it may be well to describe briefly how the subway dust was regarded in its relation to the health of the subway employees.

1. *Chemical Composition.* — There was nothing about the chemical composition of iron particles to make them especially dangerous. They were not like lead and other poisonous dusts in this respect. If the subway dust had been composed of silica, its action would have been no different.

2. *Mere Quantity.* — The amount of the dust which was breathed was not great enough to be injurious solely on account of its bulk. In this respect the atmosphere of the subway was wholly unlike that of flour mills and cement mills. There the quantity was vastly greater.

3. *Bacteria.* — Dust when breathed may cause disease by carrying bacteria into the throat and lungs. This was a matter worthy of some attention, in view of bacteriological conditions in the subway already described. Particles of dust which carry harmful bacteria are among the most injurious kinds of dust.

4. *Mechanical or Physical Composition.* — Dusts whose consistency most resembles that of the organs which they invade are least harmful, so far as physical composition is concerned. The more jagged in outline and resistant in texture, the greater is the capacity of the particles to do harm. They irritate the delicate organs with which they come in contact, and so open the way for the entrance of pathogenic microbes. The most injurious of all dusts are composed of iron and steel.

So far as the subway dust was examined, the mechanical and bacterial conditions were of most interest.

Contributing Factors

Various factors predispose persons to respiratory dust diseases. Among these may be mentioned:

1. The existence of some respiratory disease already, as, for example, tuberculosis.

2. Predisposition to respiratory disease, whether this predisposition is inherited or constitutional, increases susceptibility.

3. A neurotic condition, in which the person anticipates or expects evil effects to follow the inhalation of a dusty atmosphere, increases the liability.

4. Exertion, requiring the breathing of unusually large quantities of air, bringing into the lungs more dust, must be recognized as a contributing factor. Mouth breathing may be included in this category.

5. Humid air, draughts, or an atmosphere in which rapid changes of temperature occur, contribute to the evil possibilities of dust.

6. An especially severe use of the voice is unfavorable.

Of all these factors, the amount of air breathed, the atmospheric changes, and the severe use of the voice seemed to be especially worthy of consideration.

Natural Defenses against Dust

In normal health the delicate structure of the lungs is protected in various ways against the entrance of dust particles from the air.

1. The nose and throat are themselves effective barriers. Only a very small proportion of the dust particles which enter the mouth or nose escape the moist and irregular channels which lead to the throat.

2. If a particle passes the mouth or nose, it is almost certain to be arrested by the mucous membrane of the trachea and lower air passages. Here myriads of moving cilia carry it to a point from which it can be removed by the conscious mechanism of coughing.

3. If the particles go further they enter the bronchioles, and from there pass to the air cells of the lungs.

4. When particles of dust reach the air cells they do not necessarily pass into the tissues. They do so only when they penetrate the endothelium with which these cells are lined.

Minute foreign substances may, however, be taken into the tissues before reaching the air cells of the lungs, especially when the normal activity of the mucous membrane is reduced. This is not uncommon among persons who breathe a dusty atmosphere. When particles are absorbed, whether in the throat or lungs, they generally enter the lymphatics and are retained by the nodes or filtering arrangements with which the lymphatic system is provided. Only in rare instances do foreign particles penetrate through the lymphatic system to the blood.

Infection through pathogenic microbes occurs when the protective barriers peculiar to the surfaces of the delicate mucous lining of the air passages become injured and the natural resistance toward them

is reduced. It is not improbably due largely to the constant irritation produced by dust upon the mucous membranes that respiratory diseases are so common among city dwellers.

Condition of Throats and Lungs of City Dwellers

Respiratory diseases are extremely common among persons who live in cities, pneumonia being frequently recorded as the leading cause of death, with tuberculosis following closely. Bronchitis and laryngitis are probably equally common, though less fatal, and pharyngitis and rhinitis still more prevalent. The minor affections not infrequently lead to the more serious.

When examined after death the lungs of city people can easily be distinguished from those of dwellers in the country, the bright, rosy color which is natural to the latter being changed to gray and sometimes to black by particles of soot and dust which have got into them from the air.

Mingled with the dust in the lungs of city dwellers are particles of iron. So great is the wear of iron, particularly from the wheels of vehicles, the brakes of street and elevated railway cars, and the shoes of horses, that it was impossible during this investigation to find a specimen of dust in New York which did not contain particles of metallic iron. Iron particles were collected from the surface of fresh snow on Liberty Island in the centre of New York Bay, a mile or more from the nearest land, thirteen days after an earlier snowstorm had covered the ground and kept dust from being blown from places where it had settled. White marble buildings in New York lose their original color in some situations within a year and become noticeably yellow. The amount of this iron dust which gets into the lungs is extremely small, but it can be detected by the microscope and by analysis.

It seems unnecessary to refer to other dusty particles which get into the lungs of city dwellers. The city streets are notoriously dusty. The dust consists of a pulverized mass of refuse in which building sand, ashes, and dry horse manure are conspicuous ingredients. The tendency of this dust is to settle to the earth, but excepting after rain or snowstorms it never is absent from the air. No building in New York is high enough to escape it. It is most objectionable in the crowded streets. At a single breath a pedestrian may take into his nose or mouth a greater quantity of dust than the average subway employee gets in a month.

Because of the peculiarly large amount of iron in the dust of the subway, the disease known as siderosis, which exists most commonly among metal polishers, knife grinders, and others engaged in working in metal, will now be given separate consideration.

Disease Due to Iron Dust

The inhalation of iron dust produces evil effects in three ways:

1. By diminishing the respiratory efficiency of the lungs through a loss in their elastic property.

2. By reducing the resistance of the organs to invasion by harmful bacteria.

3. By infecting the lungs through a transportation of disease germs to places favorable for their inoculation.

The earliest symptoms of siderosis are catarrh and bronchitis, but shortness of breath is pronounced by all authorities to be the most characteristic symptom. Eventually there follows what appears to be phthisis without the presence of tubercle bacilli. Yet genuine infective phthisis is the most common cause of death.

The cause of the unpleasant symptoms is sometimes not discovered until the exposure has been endured for years, depending upon the amount of dust in the air and the personal resistance to it. Even in fork grinding, the most dangerous of dusty occupations, the effects may be delayed for decades.

Probably a great many men engaged in dusty occupations pass their lives without suspecting the cause of the uncomfortable symptoms which they experience. There is no doubt that large numbers die from infectious pulmonary diseases who do not know that the breathing of excessively dusty air has led to their infection.

A writer in a recent periodical[1] has shown the startlingly high rate of death among various classes of metal workers in America who are apparently in ignorance of the peculiar danger of their occupation.

The death rate among steel grinders and others at Solingen, Germany, for the ten years 1885–95 is shown in the following table, in which the number of deaths from consumption is given in 1,000 deaths from all causes in Germany.[2]

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[1] *The Independent*, "A Story of the Death Claims." Andrew Hellthaler. December 27, 1906.

[2] Handbuch der Medizinischen Statistik. F. Prinzing. Jena, 1906, p. 489.

TABLE III

DEATH RATES FROM PHTHISIS AT SOLINGEN, 1885–1895

Age.	Grinders.	All males.
14-20	25.8	40.0
21-30	84.4	69.9
31-40	75.9	47.0
41-50	79.3	36.0
Over 50	68.7	25.8
Over 14	72.5	35.3

DESCRIPTION OF THE SUBWAY EMPLOYEES

Of the force of about 3,000 men employed by the Interborough Rapid Transit Company to operate the subway, about 800 were motormen, conductors, or guards upon the trains, about 800 ticket sellers, ticket takers, or porters at the stations, and about 1,400 switchmen, trackmen, mechanics, painters, engineers, or others engaged on the road, in the shops, power houses, or elsewhere. This investigation was restricted chiefly to the uniformed force, consisting of trainmen and station men.

All who occupied responsible positions with respect to the operation of the trains were examined physically by the company before they were employed, records being kept of their age, weight, height, respiratory capacity, sight, color sense, hearing, and heart action.

Absences from work for less than two weeks were not, as a rule, inquired into by the company, but in the event of serious sickness the men were examined medically before they were allowed to resume their work.

The employees sent by the company for examination were, at the author's request, forty-five motormen, forty-five conductors, and ten switchmen, this list including employees who had been longest on the road and whose work had kept them most closely under conditions similar to those experienced by the traveling public.

PHYSICAL APPEARANCE OF THE MEN

Nearly all of the men were of fine physique. Capacity to do hard manual labor was not demanded of the motormen, nor was it necessary

that the conductors should have more than ordinary strength; but inasmuch as men who were eligible to these grades were recruited largely from among persons who had had other railroad experience, it was to be expected that the physical standard would be high.

The men were all between twenty-one and forty-seven years of age. Their average height was 5 feet 8¼ inches, and their average weight 169 pounds. Their general appearance of health was excellent in fifty-two cases, good in thirty cases, and poor in only two cases.

Sixty-nine per cent. of the men claimed to be citizens of the United States. About half were city-bred.

Regular Duties of the Men

The motormen were from the regular force engaged in operating the trains. Their employment requires them to sit in a small compartment at the forward end of the car at the head of a train, where they operate a number of small hand levers. The position and duties of these men prevent them from doing any physical work. They are on duty, at most, ten hours each day.

The conductors serve in the capacity of guards, with some additional duties and responsibilities not of interest in this investigation. They are stationed between the first and second cars of the trains. They stand while at work and are required to make considerable exertion in opening and closing the heavy doors of the cars at the stations. In calling out the names of the stations amid the noise of the moving trains, the throats of the conductors are put to considerable strain.

The duties of the switchmen require them to couple and uncouple cars and switch them back and forth from one track to another at the yards and storage places. This force is largely composed of men who are in the line of promotion to motormen. Of the ten switchmen examined, four had been accustomed to railroading and two to indoor work exclusively.

Medical History before and after Entering Subway Employment

The men were asked for histories of themselves before and since entering upon their subway employment. In some cases the histories given were undoubtedly unreliable, and in a few cases the men were

evidently disinclined to talk; but in general their attitude was that of frankness and honest coöperation, and it seemed safe to put considerable reliance upon their statements.

Forty per cent. had a history of previous serious illness. Sickness had been divided proportionately between the three classes. The longest time lost through illness before going to work in the subway was five and a half months.

The average length of time that the men had worked in the subway up to the time of examination was 18.2 months. Only two men had been employed less than one year; these had been working ten months.

Thirty of the 100 men claimed to feel in better condition at the time of examination than when they first began to work in the subway; five felt in poorer health; sixty-five were unchanged. In fifty-four cases the weight had increased, this increase varying from 7¾ pounds to 15½ pounds. In eighteen cases there had been a decrease.

There were fifteen cases of illness reported to have occurred during the period of subway service. Of these only nine were affections of the respiratory apparatus. There had been three cases of tonsilitis and one case of bronchitis. In twenty-seven cases time had been lost from illness, but most of these illnesses were apparently of a trifling character. The conductors lost more time than motormen or switchmen.

Twenty-five men spoke of a metallic taste in the mouth, although this point was not mentioned by the others. In seventy-seven cases a decided and peculiar yellow stain was noted on the clothing moistened by perspiration. In fifteen cases these yellow stains were observable on the body, on underclothing, and on bedclothes even after bathing. Unusual drowsiness was mentioned in forty-six of the fifty cases inquired into.

In fifty-seven cases some sort of precaution, such as douching, was taken by the men to protect the nose and throat. In seventeen cases the nose and throat were douched every day.

RESULTS OF THE PHYSICAL EXAMINATIONS OF THE EMPLOYEES

Usually forty minutes were consumed in examining each man. The eyes, nose, and throat were first examined. The men were then required to strip to the waist and an examination was made of the organs of the thoracic and abdominal cavity. Measurements of the chest com-

pleted the examination. All observations and verbal information gathered from the men were noted in blank forms prepared for the purpose.

Examination of Principal Organs and Eyes

In nearly all cases the principal organs were in good condition. The average pulse rate was eighty-five, the highest 104, and the lowest fifty-six. The cervical glands were enlarged in sixteen cases.

The eyes were found to be slightly red or irritated in 39 per cent. of the men, but there was no congestion of the ocular conjunctiva. These conditions were no more prevalent in one class than in another.

Examination of the Upper Air Passages

Abnormal conditions found in the nose and throat differed only in degree from those usually found in dwellers in cities. Bony irregularities favor catarrhal conditions, and these were probably responsible for a good many of the cases of catarrh noted in these examinations.

In sixty-eight cases rhinitis was found. It was marked in two conductors and two motormen. Bony abnormalities of the nose existed in forty-five cases.

Forty-three of the men gave a previous history of catarrh. Fifty-four had catarrh at the time of the examination, twelve of whom considered that it had developed in the subway. Catarrh was slightly more prevalent among the motormen than conductors.

In seventy-seven cases the catarrhal secretion was black, brown, green, or dirty. There was no difference between the conductors, motormen, and switchmen in this particular. It was described as from the throat in all cases except one.

Pharyngitis occurred in seventy-two cases, of which fifty-three were acute or subacute. There was about as much pharyngitis among the motormen as conductors.

Laryngitis occurred in eight cases. A slight congestion was present in forty-seven cases.

Examination of the Lungs

Cough was present in twenty-eight cases. In only one case was it considerable. The chest configuration was "good" or "excellent" in eighty cases. It was "poor" in one case. The average circumference was 90.1 cm.; the lowest 80 cm.

Six per cent. of the men gave a family history of tuberculosis. There were five cases of bronchitis, three of which occurred among the conductors.

Slight emphysema, antedating the beginning of subway employment, occurred in two cases, both among conductors.

In thirteen cases slight pains were described. They were usually in the side or in the shoulder blade.

Dry pleurisy was present in fifty-three cases. It was axillary in forty-four cases; bilateral in seventeen cases; at the apex in twelve cases. It was distributed proportionately among the three classes of men examined.

Slight infiltration was present in thirteen cases. It was combined with pleurisy in eight cases.

There were five cases of slight fibrosis, all among the motormen. Three of these cases were described as doubtful; they were combined with pleurisy.

RESULTS OF ANALYSES OF SPUTUM, URINE, AND SWEAT

Laboratory tests were made of sputum, urine, and sweat with the object of throwing light upon the findings of the medical examinations.

The specimens of sputum were in every case stained and examined microscopically for tubercle bacilli. None was found. The presence of other bacteria and macerated epithelium from the mouth was frequently noted, but proved nothing of importance.

Specimens of sputum were examined for iron. After some experiment with different methods, the test adopted was the digestion of fresh sputum with strong hydrochloric acid and the addition of ammonium sulphocyanide. Particles of iron were frequently found, but it was impossible to say that they came from the lungs. In fact, in practically every case the specimens of sputum were only secretions from the mouth and throat. Satisfactory specimens from the bronchi could probably only be obtained, if at all, from the first expectoration of the early morning. Such specimens were requested of many of the men, but were never furnished.

A few samples of urine were examined for iron. The test employed was the same as that used in examining sputum. No evidence of iron was discovered. If present at all, the amount was extremely slight.

The sweat was examined for iron for the reason that the under-

clothing of many of the employees became stained yellow where the ordinary marks of perspiration might alone be expected. The color of these stains suggested iron. Apparently the stains came from iron dust dissolved upon the surface of the body and were not due to the condition of the sweat which was exuded from the skin. It was impossible to tell from the tests the source of the iron, but the fact that the bodies of most of the men contained iron particles, and the fact that the samples of sweat were not free from skin dirt, probably offers sufficient explanation of this condition.

RESULTS OF THE AUTOPSIES

Autopsies were performed upon the bodies of five employees and one other person killed in the subway during the year 1906. Four of the employees were trackmen; one had been employed six months, two two months, and one three months. In addition there were a switchman and a guard who had been employed a year each. All were of fine physique and below forty years of age. Most of the men were Italians and had come from Italy, where they had led an outdoor life.

The autopsies showed but few of the conditions which have been described in medical literature as characteristic of siderosis and other dust disease. The bodies were usually black with the peculiar dust of the subway, but a surprisingly small amount of this dust was found within. Iron particles were extremely hard to find in the trachea, bronchioles, and air cells of the lungs, notwithstanding the fact that the men had been run over and had probably gasped dusty air directly in through the open mouth while expiring. The air passages were invariably in a normal condition for city dwellers. The lymphatics contained metallic iron, but not in overwhelming amount. Particles of iron could now and then be found in the alveoli. With the iron particles were masses of other comminuted foreign matter, chiefly soot. The lungs had lost nothing of their spongy character. There were no bands of hard fibrous tissue running through them, as might be expected in siderosis. The walls of the bronchial tubes were not thickened.

A slight diffuse pleurisy was found in all cases, but iron particles did not exist in greater amount in the areas affected by this pleurisy than elsewhere. It is doubtful whether any of these pleurisies would have been discoverable before death.

The test for iron was essentially the familiar hydrochloric acid-and-potassium ferrocyanide method. The iron particles were also recovered by incineration.

The lungs of the subway employees autopsied contained somewhat more iron than a lung which was assumed to be normal, but this normal lung contained no metallic iron at all. Inasmuch as it is probable that the lungs of all persons who have lived a few months in New York contain iron particles in sufficient number to be detectable by the delicate method of analysis employed, it seems likely that the standard of comparison used was unreasonably severe. It may be said, therefore, that the autopsies threw no light either on the possibly evil effects of the dust or the prevalence of dry pleurisy. It would be equally unfair to assume that the dust was or was not injurious when breathed under the circumstances which surrounded these men. To settle this question would require many more autopsies, and it would be essential to have them performed upon the bodies of persons who had been longer exposed to the air.

POSSIBLE CAUSES AND CONSEQUENCES OF THE PLEURISY FOUND

That an unusually large amount of pleurisy existed among the subway employees had not been anticipated. It could not at once be explained. Its importance depended apparently upon whether it was due to dust or other conditions peculiar to the subway, and whether it was associated with some physiological condition still more serious.

It thus became desirable to inquire very carefully into the nature of the pleurisy and the conditions with which it was connected. These studies were too extensive to be fully reported here, but it seems desirable that some of their more essential features should be recorded.

Pleurisy, or pleuritis, as it is more accurately called, is an inflammation, or the result of an inflammation, of the pleural membrane which surrounds the lungs. This membrane has been likened to two sacks, which are partly in contact, one within the other. The inner pleura closely covers the lungs, while the outer lines the ribs and other tissues of the chest cavity. In health the surfaces of the two pleura are very smooth and glide over one another without perceptible friction as the lungs expand and contract in breathing. In pleurisy this smoothness disappears when the inflammation occurs. Eventually

the opposing surfaces become rough or adherent, a condition which can be detected when a stethoscope is applied to the outside of the chest wall. When the friction sounds are very pronounced, they are technically described as friction rubs, and when less so, crepitant rales.

Dry pleurisy, when chronic, is in most cases the result of the more common acute pleurisy with effusion, yet there is a primitive dry pleurisy which may occur without any of the symptoms which generally accompany pleurisy of the latter sort. Pain and a characteristic cough usually call attention to the existence of pleurisy. It was a remarkable fact, repeatedly noted with surprise by the medical examiners, that the subway employees rarely complained of pain, cough, or any other of the clinical symptoms of pleurisy.

The causes of pleurisy are believed to be generally microbic. Numerous harmful bacteria have been known to reach the pleura and set up inflammation. It is also a frequent complication in pneumonia and bronchitis and is associated to some extent with tuberculosis.

The frequency with which pleurisy is noted in autopsy in connection with other diseases of the respiratory organs is shown in Table IV, made from data kindly supplied by Professor F. B. Mallory, Associate Professor of Pathology, Harvard Medical School.

TABLE IV

FREQUENCY WITH WHICH PLEURISY WAS FOUND AT AUTOPSY IN 1,008 CASES OF OTHER RESPIRATORY DISEASES AT THE BOSTON CITY HOSPITAL, 1901–1905

Year.	Number of autopsies.	Number of cases of lobar pneumonia.	Number of cases of broncho-pneumonia.	Number of cases of acute pleurisy.	Number of cases of chronic pleurisy.	Number of cases of tuberculosis of lungs.	Number of cases of tuberculous pleurisy.
1901	177	32	37	34	110	44	. .
1902	213	24	40	12	94	23	1
1903	211	23	38	30	113	46	1
1904	200	24	72	35	117	45	1
1905	207	27	33	29	84	19	2
Total	1,008	130	220	140	518	167	5

This table shows that pleurisy existed, with other respiratory diseases, to the extent of 65.8 per cent. In most cases these other diseases were probably the inciting cause of the pleurisy.

In a way not yet entirely explained a sudden chill is an important factor in producing pleurisy. A slight dry pleurisy may follow almost

immediately upon exposure. The onset may resemble the onset of pleurisy with effusion, yet after a few days the symptoms disappear and no effusion occurs. A large percentage of the pleuritic adhesions seen after death are believed to originate in this way. Dry pleurisy is never fatal. Extensive adhesions, it would appear, might seriously interfere with the normal action of the lungs, but if it does so its effects are not serious. The importance of dry pleurisy depends chiefly upon the other diseases with which it is associated. People die of the diseases which have led to the pleurisy. In seeking to explain the condition of the subway employees, therefore, it seemed desirable to look carefully for respiratory affections.

Pleurisy among the Subway Employees

For purposes of study the records of the cases of dry pleurisy among the subway employees were gathered together into two groups, according to the friction sounds by which the pleurisy had been diagnosed. These were designated: Group I, Pleuritic Crepitations, and Group II, Pleuritic Rubs.

Cases of dry pleurisy in men who reported that they had experienced an attack of pleurisy or pneumonia before entering the subway were considered sufficiently accounted for and excluded from further study. This reduced the number from fifty-three to forty-five cases. Finally, one case, suspicious of a former attack of tuberculosis, was excluded, leaving forty-four cases of dry pleurisy unaccounted for.

The following data show where and to what extent friction sounds were heard and the condition of the nose and throat in each group:

Group I. Pleuritic Crepitations; Twenty-seven Cases

Distinctness of Crepitations		Location of Crepitations	
Very distinct	1	Apex	3
Distinct	12	Axilla	20
Slight	14	Apex and axilla	4
	27		27

With these the following conditions of the nose and throat were noted:

Rhinitis		Pharyngitis		Laryngitis	
Marked	2	Marked	0	Marked	1
Present	8	Present	1	Present	10
Slight	7	Slight	13	Slight	11
	17		14		22

The foregoing data show that the pleurisy was located mostly in the axilla. It was generally accompanied by pharyngitis and slight laryngitis, and rhinitis was present in about half the cases in Group I.

GROUP II. PLEURITIC RUBS; SEVENTEEN CASES

DISTINCTNESS OF RUBS		LOCATION OF RUBS	
Very distinct	6	Apex	2
Distinct	11	Right axilla	5
Slight	0	Left axilla	10
	17		17

The following conditions of the nose and throat were noted in these cases:

RHINITIS		PHARYNGITIS		LARYNGITIS	
Marked	2	Marked	2	Marked	0
Present	3	Present	4	Present	1
Slight	11	Slight	10	Slight	11
	16		16		12

It will be observed that in Group II the pleurisy was located chiefly in the axilla, more often in the left than in the right side. It was in all but one case accompanied by slight rhinitis, and usually by pharyngitis and laryngitis.

There is considerable similarity between the data thus collated for the two groups. The friction sounds were found in the axilla as a rule. In more than half the cases there was congestion or inflammation of the nose and throat, this condition being very slight among the cases contained in Group II, in which the pleurisy was most marked.

A rather large amount of congestion and inflammation of the nose and throat existed among the employees who were apparently quite free from pleurisy. The following data illustrate this by showing the frequency with which laryngitis, pharyngitis, and rhinitis occurred among all the employees included in this study:

Number of men.	Employees.	RHINITIS.		PHARYNGITIS.		LARYNGITIS.	
		Cases.	Per cent.	Cases.	Per cent.	Cases.	Per cent.
47	Without pleurisy . .	28	60	29	62	24	51
44	With pleurisy . . .	34	77	34	77	21	47
91	Difference	6	17	5	15	3	4

These studies showed that the condition of the men with and without pleurisy was in almost all ways identical, although among those who had pleurisy there was a little more rhinitis and pharyngitis but less laryngitis than among those who were without it.

Among the forty-four cases only one complained of sore throat, although seven said that their throats became slightly dry, and seven complained of hoarseness. In thirty-five cases the men spoke of a slight expectoration, thirty describing it as "black," "gray," "dark," "dirty," or "green," and three "white." Pain was mentioned in eight cases. It was always described as slight or occasional. In five instances the pain was in the shoulder, or axilla, and in two cases in the chest.

Normal Amount of Pleurisy among City Dwellers

In order to determine just how excessive was the prevalence of dry pleurisy among the subway employees, it seemed desirable to inquire how often this disease occurred among persons engaged in other occupations.

It was well to know that dry pleurisy in its milder forms frequently existed among persons in good health and that it was extremely rare to find a body after death free from a roughened or adherent pleura, but just how commonly pleurisy occurred to the extent noted among subway employees could not be determined from the literature of the subject. It had to be sought by special investigation.

Two hundred persons were therefore subjected to a physical examination of the lungs similar to that given the subway employees. The work was done by the same principal examiner. The men examined represented a large number of vocations and were chosen at random from among persons admitted to Bellevue Hospital for various causes.

It was found that dry pleurisy existed in the same degree as met with among subway employees to the extent of 14½ per cent. If allowance had been made for their medical histories, deducting old pleurisies, emphysema, and pneumonia from the count, as had been done in studying the records relating to the subway employees, this percentage would have been slightly reduced.

Among the 200 outsiders the pleuritic sounds were noted in the axilla in twenty-two cases and in the apex in seven cases. This was about the same ratio as found among the subway employees. The diagnostic signs noted were crepitant rales twenty-five times and fric-

tion rubs four times. Among the subway employees the occurrence of rubs was relatively more frequent; in other words, the pleurisy was more marked.

The cases of dry pleurisy found among men engaged in the various employments are shown in Table V.

TABLE V

OCCUPATIONS OF PERSONS FOUND TO HAVE DRY PLEURISY

Occupation.	Cases of pleurisy.	Occupation.	Cases of pleurisy.
Butcher	2	Street cleaner	1
Driver	3	Conductor	1
Laborer	4	Real estate	1
Iron worker	2	Janitor	1
Steam fitter	1	Poleman	1
Clerk	1	Gardener	1
Porter	1	Tunnel worker	1
Brass polisher	1	Laundryman	1
Horse clipper	2	Orderly	1
Cook	1	Oysterman	1
Roofer	1		
	19		10

Of these twenty-nine cases, six were among persons engaged in dusty work.

The records relating to the forty-four cases of pleurisy which had not thus far been explained were next examined in the hope of determining whether a knowledge of the previous occupations of the employees would throw any light upon their condition. This study proved more satisfactory than was anticipated. The leading facts of interest concerning the histories of the men are given in Table VI, which is divided into two parts in accordance with the severity of the pleurisy as indicated by the diagnostic signs, pleuritic rubs, and pleuritic crepitations.

TABLE VI

LENGTH OF SERVICE IN THE SUBWAY AND IN PREVIOUS OCCUPATIONS OF EMPLOYEES WITH PLEURISY

PART I. DIAGNOSTIC SIGN — PLEURITIC RUBS

No.	SUBWAY EMPLOYMENT.		PREVIOUS EMPLOYMENT.	
	Grade.	Period of service.	Occupation.	Period of service.
1	Motorman	20 months	Locomotive fireman	6 years
2	Motorman	21 months	Conductor	11 years
3	Motorman	19 months	Locomotive fireman (5), motorman (3)	8 years
4	Motorman	19 months	Motorman	5 years
5	Motorman	15 months	Storekeeper	19 years
6	Motorman	21 months	Locomotive engineer	14 years
7	Motorman	21 months	Locomotive fireman (7), engineer (9)	16 years
8	Motorman	9 months	Motorman	10 years
9	Motorman	22 months	Locomotive fireman (9), engineer (5)	14 years
10	Motorman	17 months	Locomotive fireman (3), brakeman (3)	6 years
11	Motorman	22 months	Motorman	5 years
12	Conductor	20 months	Janitor	8–9 years
13	Conductor	16 months	Motorman	9 years
14	Conductor	16 months	Dry goods	8 years
15	Conductor	16 months	Motorman (1½), furrier (12)	13½ years
16	Conductor	26 months	Tamper	8 years
17	Conductor	16 months	Iron worker	17–18 years

Of the seventeen employees in which dry pleurisy was diagnosed by pleuritic rubs, six had, previous to their subway employment, been locomotive engineers, firemen, or brakemen, with an average period of service in these vocations of 10.1 years each. Of the remaining eleven, six had been motormen or conductors, with an average period of service of 8.6 years. Of the remaining five, one had been an iron worker for eighteen years.

TABLE VI — *Continued*

LENGTH OF SERVICE IN THE SUBWAY AND IN PREVIOUS OCCUPATIONS OF EMPLOYEES WITH PLEURISY

PART II. DIAGNOSTIC SIGN — PLEURITIC CREPITATIONS

No.	SUBWAY EMPLOYMENT.		PREVIOUS EMPLOYMENT.	
	Grade.	Period of service.	Occupation.	Period of service.
1	Motorman	19 months	Motorman	3 years
2	Motorman	19 months	Conductor	10 years
3	Motorman	21 months	Locomotive fireman (3), storekeeper (6)	9 years
4	Motorman	15 months	Locomotive fireman (3), iron molder (5), steam fitter (11)	19 years
5	Motorman	21 months	Locomotive fireman (3), brakeman (4)	7 years
6	Motorman	9 months	Locomotive fireman (9), engineer (7)	16 years
7	Motorman	24 months	Motorman	20 years
8	Motorman	10 months	Locomotive fireman (18), motorman (4)	22 years
9	Motorman	16 months	Locomotive fireman (3), brakeman (3), conductor (3), yardmaster (3)	12 years
10	Motorman	22 months	Switchman	18 years
11	Motorman	22 months	Brakeman	10 years
12	Switchman	22 months	Office clerk	10 years
13	Switchman	16 months	Locomotive fireman	2 years
14	Switchman	15 months	. . . . .	. . .
15	Switchman	16 months	Expressman	5 years
16	Switchman	16 months	Conductor (trolley)	4 years
17	Conductor	22 months	Clerk	7½ years
18	Conductor	19 months	Elevator man	5 years
19	Conductor	24 months	Inspector (2), bartender (7)	9 years
20	Conductor	16 months	Conductor (5), salesman (14)	19 years
21	Conductor	16 months	Locomotive fireman (5), railroads (20)	25 years
22	Conductor	16 months	Machinist	12 years
23	Conductor	16 months	Conductor (trolley)	13 years
24	Conductor	16 months	Leather goods	7 years
25	Conductor	21 months	Clerk (1), contractor (19)	20 years
26	Conductor	16 months	Rubber goods (1½), truck gardener (5)	6½ years
27	Conductor	20 months	Fireman (2), grocery clerk (10)	12 years

Of the twenty-seven employees whose pleurisy was diagnosed by pleuritic crepitations, nine had been locomotive engineers, firemen, or brakemen, with an average term of railway service of 7.4 years. Of the remaining eighteen, seven had been motormen, conductors, or switchmen, with an average period of 10.4 years.

Here were twenty-eight men who had, previous to their subway work, been engaged in employments in which they were exposed to alternate heat and cold to a remarkable and unusual extent for an average of nine years each.

It seemed impossible to avoid the conclusion that the excessive amount of dry pleurisy was largely the result of forgotten or unrecognized attacks of pleurisy experienced by the men before they entered upon their subway work. Many circumstances favored this opinion, among which may be mentioned the absence of pain or other clinical symptoms of acute pleurisy, absence of pneumonia, tuberculosis, or bronchitis, and the excellent health records of the men since going to work in the subway. Furthermore, there was as much pleurisy among the motormen as conductors, while their exposure both to draughts and dust in the subway was quite different, the motormen shut up in their small compartments being well protected, and the conductors standing between the cars being much exposed.

Subtracting the twenty-eight cases of pleurisy thus explained from the forty-four cases which had been without explanation left sixteen cases finally unaccounted for. This was about the normal.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The principal conclusions reached by the author concerning the various subjects dealt with in this investigation follow:

1. The air of the subway, as judged by analyses and by careful studies of the health of the men, was not injurious.

2. The most objectionable feature of the air was the dust, which consisted chiefly of angular particles of iron. It was possible, also, that injurious bacteria might sometimes be associated with these metallic particles. Lack of strict enforcement of the city ordinance against spitting, and the want of skillful care in cleaning the subway, made this danger greater than it need be.

3. The odor and heat of the subway, although very disagreeable, were not actually injurious to health. The strong draughts and changes of temperature which occurred at the stations were the most objectionable atmospheric conditions, so far as health was concerned.

4. The employees submitted by the company for physical examination were a particularly robust lot of men. From their excellent

physique it appeared that they had been carefully selected, a fact which was explained when it was found that a large majority of the men had previously been engaged in railroading, where capacity to do hard manual labor was required. It was fair to assume that the employees examined represented a fair average of all those who came in close contact with the passengers, so far as resistance to disease was concerned.

5. There had been very little sickness among the employees during their period of subway employment, judging by the accounts which the men gave. No information with respect to this matter was obtainable from the operating company. Many of the men claimed to have gained weight since they had been working in the subway—a fact due, apparently, less to any peculiarly healthful property of the air than to the easier work required.

6. Most of the men spoke of drowsiness. This was perhaps to be explained by the comparative darkness of the subway, the monotony of the work, and fatigue to the eyes. The drowsiness was never sufficient to keep the men from performing their duties properly.

7. A large number of employees complained of yellow stains which came upon their underclothing, as they supposed, from their sweat. This caused considerable inconvenience. The stains probably resulted from iron particles upon the body which were acted upon by the sweat. Investigation excluded the probability that the sweat itself was discolored.

8. Careful physical examinations showed that an excessive amount of dry pleurisy, without pain or other physical discomfort, existed among the men. Pleurisy occurred to the extent of 53 per cent. among the employees and to the extent of 14½ per cent. among persons not engaged in subway work.

The cause of the dry pleurisy was not at first apparent, but upon investigation it appeared to have been in no way due to the subway. Nine per cent. of the men had medical histories which accounted for their condition, and 28 per cent. had worked for many years under conditions known to be favorable to the occurrence of this disease. The pleurisy had no visible effect upon the health of the men and was not likely to be injurious to them in the future.

9. Congestion and inflammation of the upper air passages were prevalent. Rhinitis and pharyngitis in acute or chronic form occurred in about 70 per cent. of the men examined. Laryngitis was less common, occurring in about 55 per cent. These figures are somewhat above the normal, considering the degree of severity represented. No

case of bronchitis was discovered. The prevalence of the minor respiratory affections noted was due, apparently, more to the previous employments of the men than to their present surroundings, although the excessive use of the voice required of the conductors seemed likely to aggravate these affections.

10. Analyses of the sputum, urine, and sweat of the men showed that iron dust was given off only in the sputum. This sputum was derived mostly from the mouth and throat, where most of the iron particles drawn in with the inspired air were caught.

11. The findings at autopsy threw no light upon the possibly evil effects of the dust. The men whose bodies were examined had worked too short a time in the subway for information of value in this direction to be obtainable. Iron was found in the lungs of all, but to an extent which had produced no evil consequences.

Recommendations

Certain specific recommendations seemed to be required, under the circumstances.

1. Care should be taken that persons employed in the subway are free from respiratory disease or a tendency toward it. This rule should be extended to all grades and positions and made to apply, also, to the women who operate the news stands.

2. Thorough physical examinations, especially of the respiratory apparatus and heart, should be made of all employees when they are first engaged and at yearly intervals subsequently.

3. While the dust was not proved to have produced harmful results, sanitary considerations require that it should be prevented as far as practicable from getting into the air. To this end (*a*) sand and sawdust should not purposely be scattered on the stairways and platforms, as at present; (*b*) sweeping and cleaning should be done in a more strictly sanitary manner, preferably in accordance with the recommendations of the Advisory Board of the Department of Health; and (*c*) investigations should be made to determine whether it is feasible to reduce or collect much of the iron dust.

4. The city ordinance against spitting should be enforced to the letter. Although some progress has already been made in preventing it, spitting is still practiced occasionally on the platforms and on the roadbed. Not only passengers but employees are offenders in this direction.

BOOK REVIEWS

Chemical Annual for 1907[1]

The scope of the book is indicated by the following table of contents: Properties of the Elements and Their Factors, Physical Constants of Inorganic and Organic Compounds, Calculation of Volumetric Analyses, Calculation of Gas Analyses, Specific Gravity Tables, Equivalents of Weights and Measures, Thermochemistry, Review of Chemical Literature and New Books.

The work is to a considerable extent a translation of Biedermann's "Chemiker-Kalender," which has been so long and favorably known; besides this source, tables have been condensed from Landolt and Börnstein's Physico-Chemical Tables, Poole's "Calorific Power of Fuels," and Lewkowitsch "Analysis of Fats, Oils and Waxes."

A valuable service has been rendered by giving a wider circulation to the American Standard Baumé Tables and the Standard Table of the Manufacturing Chemists' Association of the United States for sulphuric, nitric, and hydrochloric acids, and ammonia.

A feature of the book is a list of the more important articles which have been published between January 1, 1905, and June 1, 1906, which will be appreciated by the busy man.

The work will no doubt fill a want long felt by those not conversant with German, for a fairly comprehensive, low-priced reference book, and as such may be cordially recommended. A. H. Gill.

Flow of Air[2]

Mr. C. H. Kuderer has published a table of volumes of air passing through air-ways, giving the number of cubic feet per minute through

[1] Van Nostrand Chemical Annual for 1907. John C. Olsen, Ph.D., Editor. New York: Van Nostrand, 1907. Cloth, 496 + x pp. $2.50.

[2] Table of Volumes through Air-Ways; Cubic Feet per Minute. By C. H. Kuderer. Avonmore, Pa., 1907. 25 cents.

passages 1,000 feet long, and of various sizes from 1 square foot to 100 square feet, and at various pressures from $\frac{1}{10}$ inch W. G. to 5 inches W. G. A supplementary table gives the constants for making calculations for air-ways of greater length, and an example shows the method of using the tables. Unfortunately, no reference is made to the experimental data upon which the tables are based.

A Photographer's Pocket Book[1]

This is a compact little book for the pocket of the photographer afield. It contains a sixty-page section devoted to the manipulation of plates, films, and printing papers, with special reference to the Tabloid products of Burroughs Wellcome and Company; seventy-one pages suitably ruled for detailed notes of photographic exposures; a fifty-two-page diary; twenty pages for memoranda; a Wellcome exposure calculator, and a section containing data and instructions for its use.

The paper, though of necessity very thin, is suitable for the purpose; the book is well bound, and the exposure calculator gives excellent results when used as directed. The combination is altogether an attractive one.

Self-Propelled Vehicles[2]

Nothing can remind one more forcibly of the comparatively short time since automobiles were unknown to technical literature than a sentence from Clerk's well-known text-book, "Gas and Oil Engines," published in 1896. The author states that he "has carefully examined one of the gasoline motors then coming into prominence in connection with the recent trials of motor carriages in France, . . . and finds that the engine runs at constant speed, and the whole of the operations of the carriage are performed by means of levers, clutches, change wheels, and brakes. In the author's opinion, this carriage, ingenious

[1] Wellcome's Photographic Exposure Record and Diary for 1907. New York: Burroughs Wellcome & Co.

[2] Self-Propelled Vehicles. By J. E. Homans. Theo. Audel & Co., 1907. 6th ed., 600 pp., 400 il.

as it is, will not find much use in England. A carriage, however, using heavy oils (kerosene or petroleum) . . . would probably be very successful."

Eleven years have made all the difference between this experimental stage of automobile invention and the present condition, when factories are months behind their orders and the public throngs in hundreds of thousands to learn about the latest improvements in cars exhibited at the annual auto shows In the meanwhile at least a score of books have been written to describe the horseless carriage and its accessories, only to be made obsolete as the types of engines, transmissions, carburetors, and other details have been so frequently altered.

In one of the latest practical treatises the subject has been brought down to include the 1907 models. Although written in technical language, this book cannot fail to be clear to non-technical readers, and should prove interesting and instructive to amateur automobile enthusiasts, including, as it does, practical hints on adjustment and care of the mechanisms as well as descriptions of their construction. Several chapters are devoted to the running gear, including tires, wheels, steering apparatus, and springs. In connection with gasoline engines, a brief outline of the theory involved in design and in testing for power output is given. Electric and steam-driven vehicles are also treated; considering the limited number of steam cars in use, the space devoted to boilers and steam engines is unusually large. Particularly good chapters are given on transmission gears and differential driving.

J. C. Riley.

Bulletin of the Bureau of Standards[1]

With the April number the *Bulletin of the Bureau of Standards* enters upon its third volume. An examination of the contents of this publication cannot but impress one with the high grade of scientific work being carried on in this government bureau. It is work distinctly of university grade, and is similar to that which has gone before in the two previous volumes.

The first article in the present number is by Dr. Edward B. Rosa

[1] Bulletin of the Bureau of Standards. S. W. Stratton, Director, Washington, D. C. Government Printing Office, April, 1907. Vol. III, No. 1, 161 pp., ill.

on the "Geometrical Mean Distances of Rectangular Areas and the Calculation of Self-Inductance." In this paper are discussed the corrections for insulated round wire and for the wires and layers in different parts of the coil. Tables are given of inverse tangents to nine decimal places of Stefan's equation, and a table of Napierian logarithms to nine places.

In a second paper Dr. Rosa discusses the "Compensated Two-Circuit Electro-Dynamometer."

Readers of Mr. Munsell's article in a previous number of the TECHNOLOGY QUARTERLY [1] will be interested in the article by Dr. P. G. Nutting on "The Complete Form of Fechner's Law." In this article the data for vision obtained by König and Brodhun (1888) are given in a table, and the mathematical properties of the curves are worked out, with the result that the general relation between visual sensation and stimulus is expressed by the equation

$$B = B_o \log [1 + P_m (L^c L_o^{-c} - 1)],$$

in which B = brightness, L = light expressed in meter-candles, L_o = threshold value, $P = \delta L : L$ = photometric function, P_m = minimum value of P, $B_o = \frac{1}{P_m c}$, c = a constant less than unity.

This paper is followed by one by Dr. Edward P. Hyde on "The Comparison of the Unit of Luminous Intensity of the United States with Those of Germany, England, and France." Tables are given containing summaries of the results obtained with the Harcourt, Hefner, and Carcel lamps in the national laboratories of the four countries named.

Dr. Hyde has another paper on "The Geometrical Theory of Radiating Surfaces, with Discussion of Light Tubes." In this are considered radiation from a cylinder, from a flat circular disk of 10 mm. radius, and from a uniformly radiating strip of infinite length.

Messrs. Frederick J. Bates and J. C. Blake, in a paper on "The Influence of Basic Lead Acetate on the Optical Rotation of Sucrose in Water Solution," give a curve showing the errors introduced in polarizations by various amounts of basic lead acetate in sugar solutions.

Messrs. H. N. Stokes and J. R. Cain have two papers, one on "The Colorimetric Determination of Iron," in which are described methods

[1] TECHNOLOGY QUARTERLY, March, 1905, **18**, No. 1, p. 60.

for the extraction of ferric sulphocyanate, the form of the colorimeter, and the methods for concentrating the iron, for preventing the fading of the color, and special directions for concentrating traces of iron from various substances. In the paper on "Sulphocyanic Acid," these authors give a rapid method for preparing the pure acid, with an account of some properties of the solution, and they discuss the occurrence and characteristic reactions of isodisulphocyanic and isopersulphocyanic acids.

PROCEEDINGS OF THE SOCIETY OF ARTS

FORTY-FIFTH YEAR, 1906-1907

BOSTON, February 28, 1907.

THE 633d regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, February 28, at eight o'clock, about thirty-five persons being present. Professor Mott presided. The minutes of the last meeting were read and approved.

There being no further business to come before the meeting, the chairman introduced Mr. E. S. Cole, Consulting Engineer of New York, who spoke on "Water Works Losses, and the Use of the Photo-Pitometer."[1] Mr. Cole showed the relative losses under different conditions, and gave an interesting account of the recent investigations with the photo-pitometer in New York, with the object in view of detecting both natural losses and losses due to direct theft through meter by-passes. The lecture was illustrated with thirty lantern slides. After the thanks of the Society had been tendered the speaker by the chairman, the meeting adjourned.

BOSTON, March 14, 1907.

The 634th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, March 14, at eight o'clock, about fifty persons being present. Professor C. H. Peabody presided. The minutes of the last meeting were read by the Secretary and approved.

There being no further business to come before the meeting, the chairman introduced Professor A. H. Sabin, of New York, who spoke

[1] Printed in full. See pp. 141–161.

on "Paint as a Preservative Coating." Professor Sabin's long experience in this line of work, both theoretical and practical, as a chemist and a manufacturer made his address of much interest. The thanks of the Society were extended by the chairman, and the meeting adjourned at 9.30 o'clock.

BOSTON, March 28, 1907.

The 635th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, March 28, at eight o'clock. Professor Charles R. Cross presided. The minutes of the last meeting were read and approved.

The chairman introduced Dr. L. A. Bauer, Director of the Department of Research in Terrestrial Magnetism of the Carnegie Institute, Washington, D. C.

Dr. Bauer gave a most interesting account of the work in magnetic survey[1] done both by the Coast and Geodetic Survey and by the Carnegie Institute. He showed charts of the work already done, and briefly referred to the magnetograph records of the San Francisco earthquake, showing the absolute agreement with the seismograph, and in many instances their greater sensitiveness. About forty-five persons were present. The chairman extended thanks to the speaker in behalf of the Society, and the meeting adjourned at 9.30 o'clock.

BOSTON, April 11, 1907.

The 636th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, April 11, at eight o'clock, and was called to order by Dr. Robert P. Bigelow. The minutes of the last meeting were read and approved.

Hon. Willard Howland, of Boston, was introduced and spoke on the Cape Cod Canal. Mr. Howland reviewed the history of Cape Cod Canal projects from the earliest days. He clearly showed the need of such a canal, both from a commercial and a humanitarian point of view, and showed the advantages over all others of the Sandwich-

[1] Printed in full. See pp. 170–186.

Buzzard's Bay route, which has been chosen for the present location. The large attendance of one hundred indicated the interest taken in the subject. The meeting adjourned at 9.30 o'clock, after the thanks of the Society had been tendered the speaker.

BOSTON, April 25, 1907

The 637th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, April 25, at eight o'clock. Dr. Robert P. Bigelow presided. The minutes of the previous meeting were read and approved.

The chairman introduced Mr. Frank M. Gilley, who spoke on "Trade Instruction in Holland, and the Instrument Makers' School in the University of Leyden." Mr. Gilley has made a careful study of this school, and his long service as a teacher made his comments and observations of especial value and interest. Mr. Gilley brought out the differences between trade schools in Holland and in our own country, and spoke with much interest of the results obtained by their methods. From these schools a lad is graduated at fifteen or sixteen years of age, with a trade which makes him self-supporting at once. A subsequent course at the Instrument Makers' School puts him in a position to act as an amanuensis at various colleges both at home and abroad. Their ability to make and repair all sorts of apparatus makes them especially valuable assistants.

The thanks of the Society were extended to the speaker, and the meeting adjourned at nine o'clock.

BOSTON, May 9, 1907.

The 45th annual meeting and 638th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, May 9, at eight o'clock, about one hundred and forty persons being present. The President, Dr. Henry S. Pritchett, was in the chair. The minutes of the last meeting were read and approved.

The Nominating Committee presented the following nominations for Executive Committee: Colonel Edmund H. Hewins, Mr. James P.

Munroe, Mr. Charles J. H. Woodbury, Dr. Robert P. Bigelow, Mr. William Lyman Underwood. The Secretary was empowered to cast one ballot for these gentlemen, which was done, and they were declared elected.

Walter S. Leland was nominated for Secretary for the ensuing year and was duly elected.

The report of the Executive Committee was presented by Colonel Edmund H. Hewins, chairman of the committee, and was accepted.

There being no further business to come before the meeting, the President introduced Mr. W. R. Warner, of Cleveland, Ohio, who spoke on "The Panama Canal." Mr. Warner visited the canal zone with the Congressional Committee which reported in favor of the lock canal.

The speaker showed about seventy-five lantern slides taken at various points of interest during the trip, clearly illustrating the condition of work at the canal. Several maps were thrown upon the screen showing the route, and the principal difficulties attending the construction both of a sea level and a lock canal were briefly described. Slides were also shown in which appeared the old steam shovels left by the French, some of which are in active operation, although most of them are being rapidly replaced by modern steam shovels. Mr. Warner's address gave an insight not only into the active work of construction, but also into the hospital service, views of which were shown, as were views of the engineers' quarters.

The President extended to the speaker the thanks of the Society, and the meeting adjourned at 9.30 o'clock.

WALTER S. LELAND, *Secretary.*

REPORT OF THE EXECUTIVE COMMITTEE OF THE SOCIETY OF ARTS FOR THE YEAR 1906–1907

BOSTON, May 9, 1907.

From time to time it is well to pause to consider the objects of our endeavor and how far we are attaining them. In the "Objects and Plan of an Institute of Technology" (Edition 2, 1861), President Rogers points out the connection between industrial progress and an enlarged acquaintance with the objects and phenomena of nature and with physical laws, and he speaks of the benefit which the most enlightened communities of Europe have obtained from this practical coöperation of education and the arts by the establishment of museums, societies,

and colleges of technology. He says: "With the view of securing the great industrial and educational benefits above alluded to, it is proposed to establish, on a comprehensive plan, an institution devoted to the practical arts and sciences, to be called the Massachusetts Institute of Technology, having the triple organization of a society of arts, a museum or conservatory of arts, and a school of industrial science and arts."

It will be seen that in the plan the SOCIETY OF ARTS was placed first, and in regard to it President Rogers says that "under the first of these characters" the Institute would form itself into a department of investigation and publication intended to promote research in connection with industrial science by the exhibition at the meetings of the society of new mechanical inventions, products, and processes, by written and oral communications and discussions, as well as by more elaborate treatises on special subjects of inquiry. Another line of activity proposed was the publication of a series of reports exhibiting the conditions of the departments of industry, with the progress of practical discovery in each and the discussion of the scientific questions involved. In order to carry out these plans for publication, it was proposed to found a journal, which, it was hoped, would be a powerful means for advancing the interests of the industrial arts and practical education.

With these plans the SOCIETY OF ARTS was founded, and it is with these objects in view that we have continued our activities until the present day. Advance in complexity and specialization of the various arts and sciences have resulted, however, in the formation of many special societies and in the publication of journals devoted to narrow lines of science and industry. There still remains, however, in every community the need of bringing to the attention of those who are not specialists the advances in arts and sciences which may have an influence upon the life of the people. This function may very well be filled for Boston by the SOCIETY OF ARTS. That we are accomplishing this object to some extent is shown by the gratifyingly large attendance at our meetings.

We have in the TECHNOLOGY QUARTERLY a journal which aims to fulfill the objects of the founder in regard to publication. This is done in two ways: first, by printing the Proceedings of the SOCIETY OF ARTS, and so far as possible publishing in full the communications that have been presented to the Society; second, by publishing original papers, giving the results of investigations carried on in the laboratories

of the Institute. In fulfilling the second function the TECHNOLOGY QUARTERLY is hampered by two circumstances, the most serious of these being that the investigators generally desire to publish their results in journals devoted especially to the sciences or arts to which they appertain. In order that the TECHNOLOGY QUARTERLY might be more truly representative of the work done in the Institute, a special committee of the Faculty and the Board of Publication, sitting as a joint committee, recommended the following resolution:

> That in future every member of the instructing staff be requested to send to the Editor of the TECHNOLOGY QUARTERLY a full and exact title of every volume or paper published by himself as soon as this appears. With such title he shall also be requested to send a concise and comprehensive abstract or description of the volume or paper, and if possible a copy of the same as printed. Some papers might, perhaps, be reprinted in the QUARTERLY, but in general only the title and abstract will be given.

This was adopted by the Faculty, and in coöperation with the Editor the Faculty Committee on Publications have sent out circulars in pursuance of the above resolution, and this department of titles and abstracts will appear for the first time in the TECHNOLOGY QUARTERLY for June, 1907.

The second difficulty is that lack of sufficient funds makes it impossible to print in full the results of many investigations, which consequently appear elsewhere.

During the past year the Editor has been fortunate in securing an unusually large number of papers read before the Society for publication in the QUARTERLY, and also a number of papers presented to classes of students by distinguished visitors. Besides these, several of the departments have made valuable contributions, and the book reviews continue to be an interesting feature.

During the year there have been thirteen lectures delivered before the Society, as follows:

October 28, 1906. Dr. George W. Pierce, "The Wave Lengths in Wireless Telegraphy."

November 8, 1906. William Lyman Underwood, "The Work of the River Drivers in the Maine Woods."

November 22, 1906. Dr. George A. Soper, "The Air of the New York Subway."

December 13, 1906. A. E. Brown, "The Application of Hoisting Machinery to Shipbuilding."

December 27, 1906. Richard L. Humphrey, "The California Earthquake."

January 10, 1907. H. E. Warren, "The Governing of High Pressure Water Wheels."

January 24, 1907. Dr. Walter E. Winship, "Storage Battery Regulations."

February 14, 1907. F. L. DuBosque, "The Marine Interests of a Railroad."

February 28, 1907. Edward S. Cole, "Water Works Losses, and the Use of the Photo-Pitometer."

March 14, 1907. Professor A. H. Sabin, "Paint as a Preservative Coating."

March 28, 1907. Dr. L. A. Bauer, "Recent Results of Terrestrial Magnetic Observations."

April 11, 1907. Hon. Willard Howland, "The Cape Cod Canal."

April 25, 1907. Frank M. Gilley, "Preparatory Trade Instruction in Holland, and the Instrument Makers' School in the University of Leyden."

May 9, 1907. W. R. Warner, "The Panama Canal."

The meetings have been advertised, with two or three exceptions, in the *Saturday Evening Transcript* on the Saturday preceding the lecture, but it is questionable if the attendance has been largely increased in this manner.

The attendance at the meetings has been comparatively good, the smallest number about twenty-eight and the largest one hundred and forty. Sixty seems to be the average attendance.

The membership of the Society has been decreased in the past year by ten. One new member has been elected and one cannot be found, no address being known. At present there are on the books of the Secretary three hundred and six names. Of these, fifty-four are in arrears to the extent of two years or more, the sum total of the delinquent dues amounting to $774. Since September, $921 have been collected — $729 dues of the current year and $192 arrears, varying in sums from $6 to $24. A personal letter of appeal has been sent to each of the delinquents, and it is believed that persistent efforts will result in the collection of at least half of the amount still due.

EDMUND H. HEWINS, *Chairman.*

PUBLICATIONS[1]

Biology, and Sanitary Research Laboratory and Sewage Experiment Station

E. B. Phelps.—The Prevention of Stream Pollution by Strawboard Waste. Water Supply and Irrigation Paper No. 189. United States Geological Survey, Washington, D. C., 1906.*

W. T. Sedgwick.—The Expansion of Physiology. Vice-Presidential Address, A. A. A. S., Section K, Physiology and Experimental Medicine. *Science,* N. S., Vol. XXV, No. 635, pp. 332–337, March 1, 1907.*

An address drawing attention to the recent remarkable development of the physiological side of general biology and its increasing influence upon modern thought and affairs. The theory is advanced, in explanation of the comparative neglect of physiology between 1860 and 1890, that this was due to the almost universal concentration of biological work and thought upon Darwinism and its corollaries.

Chemistry and Chemical Engineering

W. H. Walker.—An Instructive Laboratory Experiment in Applied Chemistry. *Proceedings of the American Electrochemical Society,* Vol. IX, p. 23, May, 1906.*

Civil Engineering

C. B. Breed (with G. L. Hosmer).—Principles and Practice of Surveying. New York: Wiley & Sons, September, 1906.*

G. L. Hosmer.—See C. B. Breed.

G. F. Swain.—Engineering Education, an Informal Discussion at the Annual Convention, June 27, 1906, "What Is the Best Preparatory Education for the Civil Engineering Profession?" "Is Technical Training the Best Education for Executive Work?" *Transactions of the American Society of Civil Engineers,* Vol. LVII, pp. 141–149 and 177–180.

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[1] In order that the extent of productive work carried on at the Institute may be better known, it is designed to publish quarterly a list of the publications of the officers and students of the Institute, together with abstracts when possible. In this list the publications are arranged alphabetically by departments and then alphabetically by authors.

The asterisk after the title indicates that a copy of the publication has been placed in the library of the Institute.

Drawing and Descriptive Geometry

C. L. Adams.—Notes on Descriptive Geometry, Part I. Boston: George H. Ellis, February 15, 1907.*

Electrical Engineering

G. C. Shaad.—Abstracting Engineering Papers. *Electric Journal,* Vol. IV, p. 83, February, 1907.*

English

C. H. Collester.—Notes on the "New England Short O." *Modern Language Notes,* Vol. XXII, p. 80, March, 1907.*

This article calls attention, for the first time, to certain phonetic properties of a semi-dialectic sound of *O*, heard chiefly in New England and hence known as the "New England short *O*." Some analogies and uniformities in the usage are pointed out.

Geology

D. W. Johnson.—Drainage Modifications in the Tallulah District. *Proceedings of the Boston Society of Natural History,* Vol. XXXIII, p. 211, February, 1907.*

D. W. Johnson.—River Capture in the Tallulah District, Georgia. *Science,* N. S., Vol. XXV, p. 428, March 15, 1907.*

Both papers deal with the capture of the former head waters of the Chattahoochee River by the Savannah River, the capture having taken place near Tallulah Falls, in northeastern Georgia. The longer paper presents a full account of the whole problem, reviewing the previous writings on the subject, giving a brief account of the general geology and physiography of the southeastern United States, and discussing in greater detail the geology and physiography of the Tallulah district. It is shown that many peculiar topographic features exist in the district, which demand some rational explanation. A deductive study of river capture is then made, in order to determine what features would result from the capture of one stream by its neighbor. It is found that the features which ought to result from such capture are precisely those which do occur in the Tallulah district. Strong presumption is thus given in favor of the Savannah-Chattahoochee capture, suggested by some geologists but doubted by others. Conclusive proof that the capture did occur is then offered, based on the finding of old, stream gravels along the former course of the upper Chattahoochee, where no river now flows. The evidence afforded by the distribution of the fresh-water shells, urged by some in support of the capture theory, is examined but found inconclusive, although the fact of capture is well established on other lines of evidence. Alternative theories to account for the features of the Tallulah district are examined, but do not appear satisfactory.

The shorter paper presents an outline of the argument, but deals more especially with the principal evidences of capture and the inconclusive character of the argument based on the distribution of the fresh-water shells.

Mechanical Engineering

G. Lanza.—Some Tests of Reinforced Concrete Beams. *Proceedings of the American Society for Testing Materials,* Vol. VI, 1906, Philadelphia, Pa.*

G. Lanza.—Memoirs of Deceased American Investigators Who Have Contributed in a Marked Degree to the Advance of the Testing of Materials. *Proceedings of the American Society for Testing Materials,* Philadelphia, Pa., Vol. VI, 1906.*

Mining Engineering and Metallurgy

H. O. Hofman (with R. P. Reynolds and A. E. Wells).—Laboratory Experiments in Lime-Roasting a Galena Concentrate with Reference to the Savelsberg Process. *Transactions of the American Institute of Mining Engineers,* April, 1907.*

H. O. Hofman (with W. S. Caypless and E. E. Harrington).—The Constitution of Ferro-Cuprous Sulphides. *Transactions of the American Institute of Mining Engineers,* April, 1907.*

Physics

L. Derr.—Photography for Students of Physics and Chemistry. New York: Macmillan, 1906.*

Research Laboratory of Physical Chemistry

W. C. Bray.—See A. A. Noyes.

A. A. Noyes (with W. C. Bray).—A System of Qualitative Analysis for the Common Elements. *Technology Quarterly,* Vol. XIX, No. 3, p. 191, September, 1906, and *Journal of the American Chemical Society,* Vol. XXIX, p. 137, February, 1907.

Institute Publications

Report of the President and Treasurer. *Bulletin of the M. I. T.,* Vol. XLII, January, 1907.*

Register of Graduates. *Bulletin of the M. I. T.,* Vol. XLII, March, 1907.*

Summer Courses, 1907. Boston, March, 1907.*